CAMEROON CENTRAL AFRICAN REPUBLIC CHAD NIGER NIGERIA

Integrated and Sustainable Management of Shared Aquifer Systems and Basins of the Sahel Region

RAF/7/011

LAKE CHAD BASIN

2017

REPORT OF THE IAEA-SUPPORTED REGIONAL TECHNICAL COOPERATION PROJECT RAF/7/011

LAKE CHAD BASIN

COUNTERPARTS:

Mr Annadif Mahamat Ali ABDELKARIM (Chad)

Mr Mahamat Salah HACHIM (Chad)

Ms Beatrice KETCHEMEN TANDIA (Cameroon)

Mr Wilson Yetoh FANTONG (Cameroon)

Mr Sanoussi RABE (Niger)

Mr Ismaghil BOBADJI (Niger)

Mr Christopher Madubuko MADUABUCHI (Nigeria)

Mr Albert Adedeji ADEGBOYEGA (Nigeria)

Mr Eric FOTO (Central African Republic)

Mr Backo SALE (Central African Republic)

EXPERT:

Mr Frédèric HUNEAU (France)

Reproduced by the IAEA

Vienna, Austria, 2017

Table of Contents

1. INTRODUCTION

The Lake Chad Basin is situated in the eastern part of the Sahel region at the southern edge of the Sahara Desert; it is one of the largest sedimentary groundwater basins in Africa extending over an area of about 2,381,000 km². Annual rainfall amount is strongly contrasted throughout the basin from Libya to Central African Republic varying between 1,500 mm/a in the south of the basin to less than 100 mm/a in the north. Due to high temperatures throughout the year, the potential evapotranspiration exceeds 2,000 mm per year at the centre of the basin. This phenomenon entails strong restrictions in the availability of water resources, which are unevenly distributed between the North, Centre and Southern parts of the basin. Although surface water availability can be limited especially during the dry season, groundwater is present almost everywhere in the basin at varying depths.

Unfortunately, the extent and quality of theses groundwater resource is still poorly documented and the lack on enough relevant technical information on this topic can be considered as a limiting factor for the development of the whole Chad Basin region. Groundwater is the most used source of water supply in the region for both populations and agriculture. The total population of the entire Lake Chad basin is estimated at about 47 million in 2013. The main activities are agriculture, nomadic and semi-nomadic animal husbandry and fisheries (BGR, 2012). Following a period of reduced precipitation in the 70ies and 80ies with severe droughts in 1973 and 1984, the open water surface of the Lake Chad shrank from about 18,000 km² to less than 2,000 km². The following years were marked by a high precipitation variation and a temperature increase of about 1°C, as well as a significant population growth. However, the size of the open water surface with nearly 4,500 km² has remained more or less constant since the year 2000.

The Lake Chad Basin has first been investigated in terms of isotope hydrology approaches in the late 1960's with the pioneering works of Fontes et al. (1969, 1970) and Roche (1980). They first focused on the Lake Chad water but they very fast came to hydrogeological investigations on groundwater and shallow Quaternary aquifers around the Southern Lake Chad region and N'Djamena area. In the late 1980's Ketchemen (1992), in the framework of the IAEA-supported projects CAM/8/002 and RAF/8012 (1987-1991), produced the first extensive isotope study of the swamp area of the Grand Yaéré (Northern Cameroon) followed in the 1990's by Djoret (2000) on the Chari-Baguirmi area (Chad) and Kadjangaba (2007) on the N'Djamena area (Chad), supplemented in 2008-2010 by the IAEA-supported project CHD/8/002 project also on the N'Djamena city area. In the late 1990's first investigations were carried out in the Diffa area (Niger) by Leduc et al. (2000) and Zairi (2008) and in

North-eastern Nigeria by Goni (2006) and Maduabuchi (2006). All the studies mainly and most exclusively focused on the shallow Quaternary aquifer. Very few information does exist on the isotope hydrology of deeper groundwater from the Lower Pliocene or Continental Terminal. The Central African part of the Lake Chad basin watershed has never been investigated in terms of isotope hydrology and geochemistry of groundwater. Different studies have tried to constrain the groundwater flow and infiltration processes of the Quaternary aquifer through modelling approaches with various results and different approximations (Eberschweiler, 1993; Boronina and Ramilien, 2008; Candela et al., 2014; Genthon et al., 2015; Bouchez et al., 2016). More recently detailed isotopic and geochemical investigations have been carried out in Chad by the German cooperation (2010-2016) through different projects undertaken by BGR. These very detailed hydrological, isotopic and geochemical investigations are also mainly focused on shallow groundwater of the Quaternary from the Logone-Chari floodplain, Kanem and Bahr el Ghazal regions. In 2015, Bouchez (2015) and Bouchez et al. (2015) proposed a detailed study of Chad Lake water and Quaternary groundwater interactions through the use of isotopes/geochemistry and made an attempt to evaluate the residence time of the CT aquifer groundwater through the use of ^{36}Cl in the Bahr El Gazal region of Chad.

The isotopic hydrology of rainfall has also been very poorly investigated in this region and the GNIP station of N'Djamena was only operated from 1960 to 1995. Other additional but very discontinuous and punctual data on rainfall are also available from Faure et al. (1970), Joseph et al. (1992) and Leduc et al. (2000). All the aquifers in the Lake Chad Basin are of transboundary type (TBA) and require intense attention for the sustainable resource development. However, even considering the sparse previous studies, little is known about the availability, the recharge processes, the residence time and the quality of groundwater at the whole basin scale. In the framework of the IAEA-supported project RAF/7/011, a first attempt is made to consider and interpret isotopic and geochemical data from four neighbouring countries (Chad, Niger, Cameroon and Central African Republic) on a joint basis to promote a better management of the groundwater resource shared by the different Lake Chad Basin governments based on a collective approach.

2. STUDY SITES

2.1. Location and topography

The Lake Chad Basin is an endorheic depression, covering almost 8% of the African continent (Fig. 1), with eight countries grouped around it, four of which are in direct contact with the lake: Nigeria, Niger, Chad and Cameroon. Niger and Chad are those with the largest shared territory in the whole area of the basin with respectively 29% and 44% of their territory within the limits of the watershed (Table 1). Cameroon and the Central African Republic are less represented with about 2% and 9% respectively of their territory, but three quarters of the lake water feeding come from the humid regions of CAR and Cameroon.

The basin is an extended plain mostly covered by medium to fine-grained sands. The surface height varies from 3300 m asl in the north (Tibesti Mountains); 3000 m asl in the NW (Ahaggar Mountains) and 3,300 m asl in the SW (Adamawa Plateau) to 180 m asl in the Pays Bas (lowlands at the centre of the basin).

The central part of the basin is characterized by two different landscapes subdivided by the 14°N parallel: sand dunes and the absence of surface water sources are typical for the northern part (Kanem), while the south is composed of superposition of sandy and clay richly watered by two main rivers that discharge into the lake:

The Chari-Logone River system (Chad) that supplies about 95 % of the annual volume of water that reaches the lake and the Komadougou-Yobé River system (Niger) that provides about 3 % of the annual inflow to the lake.

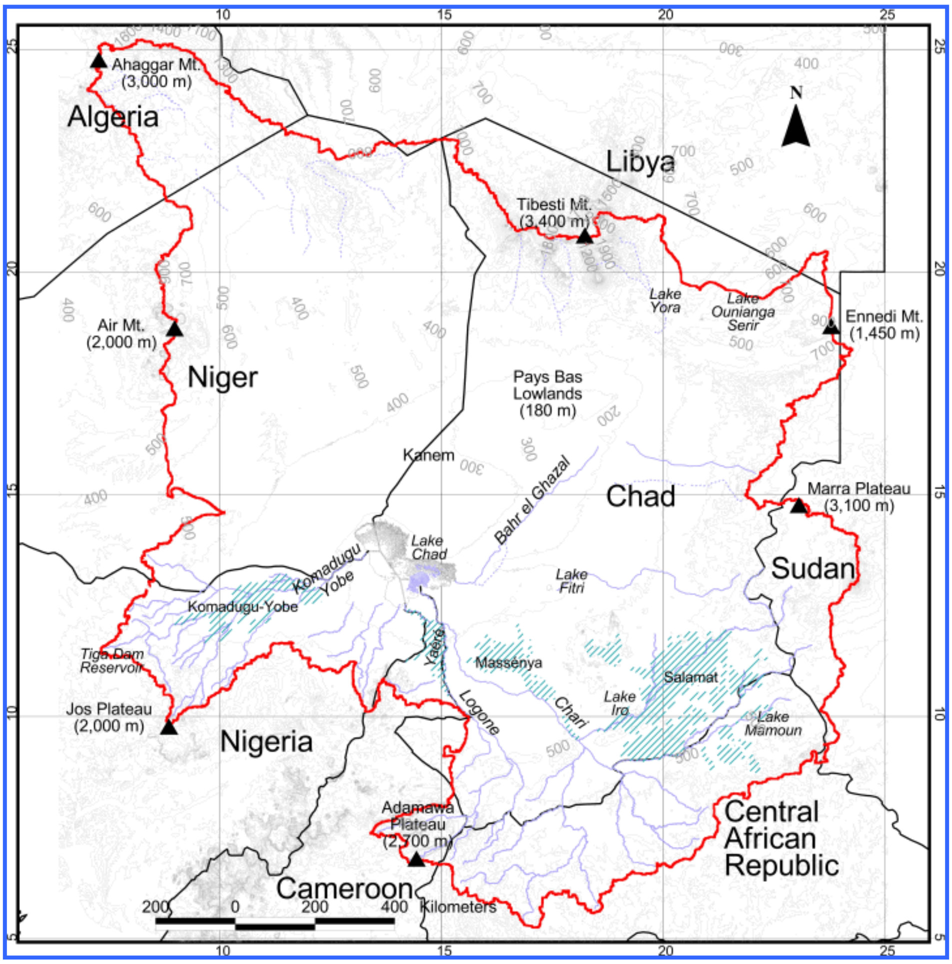


Figure 1: Extension of the Lake Chad basin and main countries concerned (*BGR, 2010)*

Table 1: The lake Chad Basin countries - Libya is not considered here because of the absence of water contribution from its territory (FAO).

Country	Total area of the country (km^2)	Area of the country within the basin (km^2)	As % of total area of basin (%)	As % of total area of country (%)	Average annual rainfall in the basin area (mm)		
					min	max	mean
Nigeria	923770	179282	7.5	19.4	285	1330	670
Niger	1267000	691473	29.0	54.6	0	635	105
Algeria	2381740	93451	3.9	3.9	0	135	20
Sudan	2505810	101048	4.2	4.0	70	1155	585
CAR	622980	219410	9.2	35.2	760	1535	1215
Chad	1284000	1046196	43.9	81.5	0	1350	400
Cameroon	475440	50775	2.1	10.7	365	1590	1010
For Lake Chad basin		2381635	100.0		0	1590	415

2.2. Climatology of the area

The climate of the Lake Chad Basin is tropical comprising four climate zones, which match the different types of isohyets. The basin belongs to the Sahelian zone in which the monsoon rainfall decreases from the south to the north (less than 100 mm of rainfall in the north of Chad, Libya and Algeria - to 1500 mm per year in the south of the basin in the south of Chad and in the Central African Republic. The climate of the Lake Chad Basin is classified in four sub-types (from the north to the south):

- The Saharan climate is characterised by less than 100 mm of rainfall per year;
- The Sahelian-Saharan climate with an average annual rainfall ranging from 100 to 400 mm;
- The Sahelian-Sudanese climate, more wet with an average annual rainfall ranging from 400 to 600 mm;
- The Sudanese-Guinean climate, with an average annual rainfall in the area ranging from 600 to 1500 mm.

The area is characterized by high temperatures throughout the year, very low humidity except during the rainy season from June to September. Intense solar radiation and strong winds lead to a high annual potential evapotranspiration of around 2,200 mm for Central Chad (Carmouze, 1976). N'Djamena (the capital), which lies in the central basin, is characterised by Sahelian steppe climate, with little rainfall (Fig. 2, Table 2).

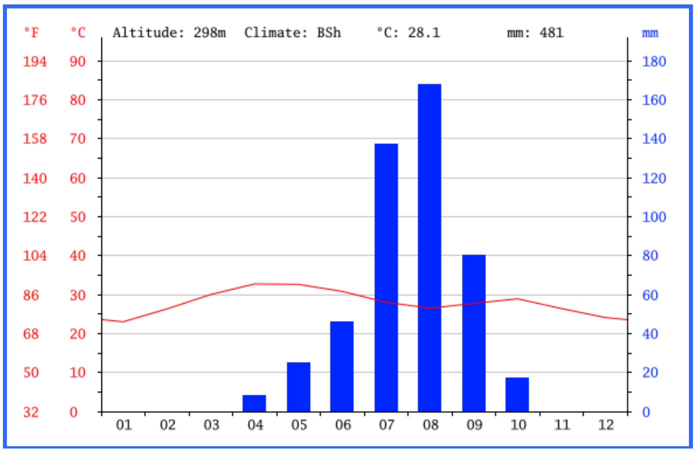


Figure 2: Monthly temperatures and rainfall at N'Djamena airport (1982-2012)

Table 2: Mean monthly weather data from N'Djamena airport station (1982-2012)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Rain (mm)	0	0	0	8	25	46	137	168	80	17	0	0	481
T (°C)	23.0	26.3	30.0	32.7	32.6	30.8	28.0	26.5	27.7	28.9	26.4	24.1	28.1

The city of Mondou, in the south of Chad, has a Sudanese-Guinean climate with much favourable rainfall conditions (Fig. 3, Table 3).

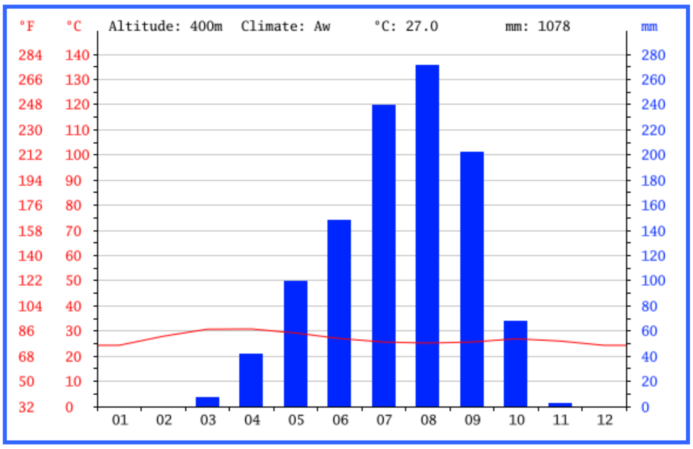


Figure 3: Monthly temperatures and rainfall at Moundou airport station (1982-2012)

Table 3: Mean monthly weather data from Moundou airport station (1982-2012)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Rain (mm)	0	0	7	42	99	148	239	271	202	68	2	0	1078
T (°C)	24.3	27.9	30.7	30.8	29.2	27.0	25.6	25.2	25.6	26.9	26	24.3	26.9

In N'Djamena region, and more generally in the whole Sahelien region, a relatively long period of rainy years extended from 1937 to 1961 that was shortly interrupted by a dry period from 1946 to 1951 and followed by a period of average rainfall up to 1979 interrupted by 4 dry years from 1972 to 1975. Thereafter precipitation decreases and a long dry period up to 1997 installed. Since then, a wet period prevails (BGR, 2016).

In the past, the whole Sahelian region has known different wet phases (Beyerle et al., 2003). Before 4500 years BP the African climate was characterised by several wet phases during the Holocene with an optimum in the Sahara region at around 8500-6500 years BP, interrupted by short dry periods (Gasse, 2000). In the Sahelian belt the monsoon reactivation after the dry and cold Last Glacial Maximum (23-18 kyr BP) took place in two steps at around 15000 and 11500 years BP (Gasse, 2000), separated by a return to drier conditions coincident with the Younger Dryas. Paleoclimate records from Africa that extend beyond the LGM indicate that before 23000 years BP wet climate conditions alternated with arid phases while the average temperature remained lower than today (Gasse, 2000, Beyerle, 2003).

2.3. Geology and hydrogeology

According the Schneider and Wolff (1992), the Lake Chad Basin is composed of a sequence of layers of different ages and thicknesses (Fig. 4).

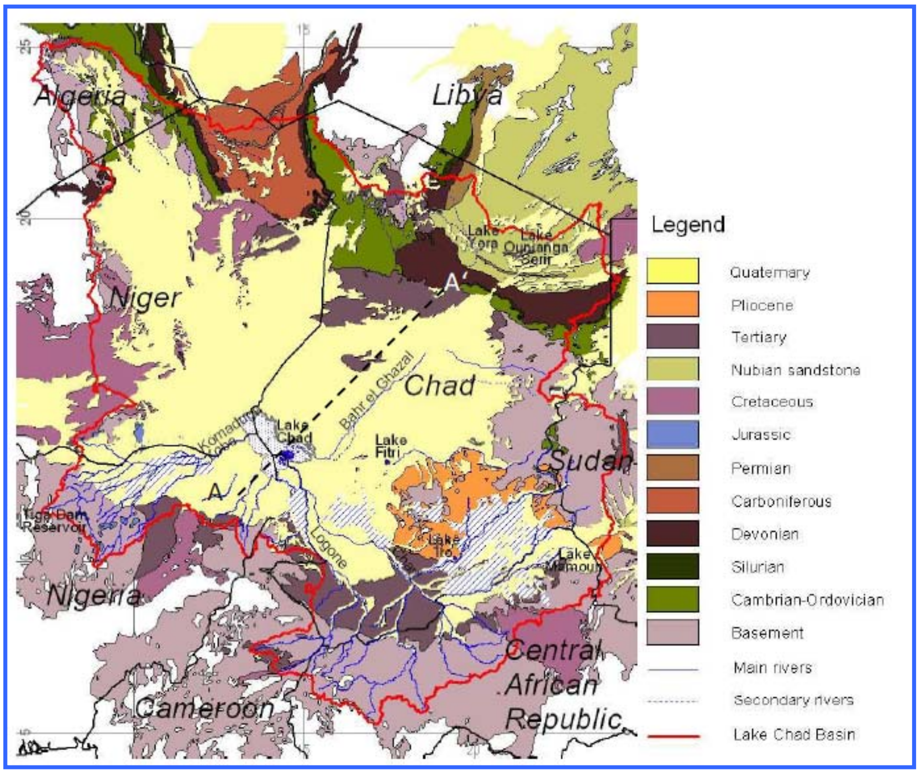


Figure 4: Geology of the Lake Chad Basin (BGR, 2012).

The deepest known layer being the Continental Terminal (Oligocene/Miocene) composed of sandstones of around 200 m in thickness and located at depths between 400 and 600 m below the surface (Fig. 5). Overlying, the Lower Pliocene composed of fluvio-lacustrine sands is encountered. The Upper Pliocene follows as a massive layer of clays of 200-300 m of thickness. The Quaternary composed the uppermost layer and is made of sands with different sub-formations as follows in the Central Chad Basin (BGR, 2014):

- The Moji Series (from early Pleistocene) which is a fluvio-lacustrine clayey series with evaporates (gypsum) to the North of Kanem,

- The eolian sand dunes of the "Ogolien" age (lying over the Moji Series) corresponding to dunes formed from 20 000 to 13 000 y BP (Swezey, 2001). These dunes appear mainly in the North of Lake Chad and are essentially composed of quartz sands. The interdunal valleys up to a distance of 30 km from the ancient lake shore are often occupied by sodium-carbonate containing evaporate minerals such as natron (Na_2CO_3, 10 H_2O) still exploited as sodium carbonate salt.

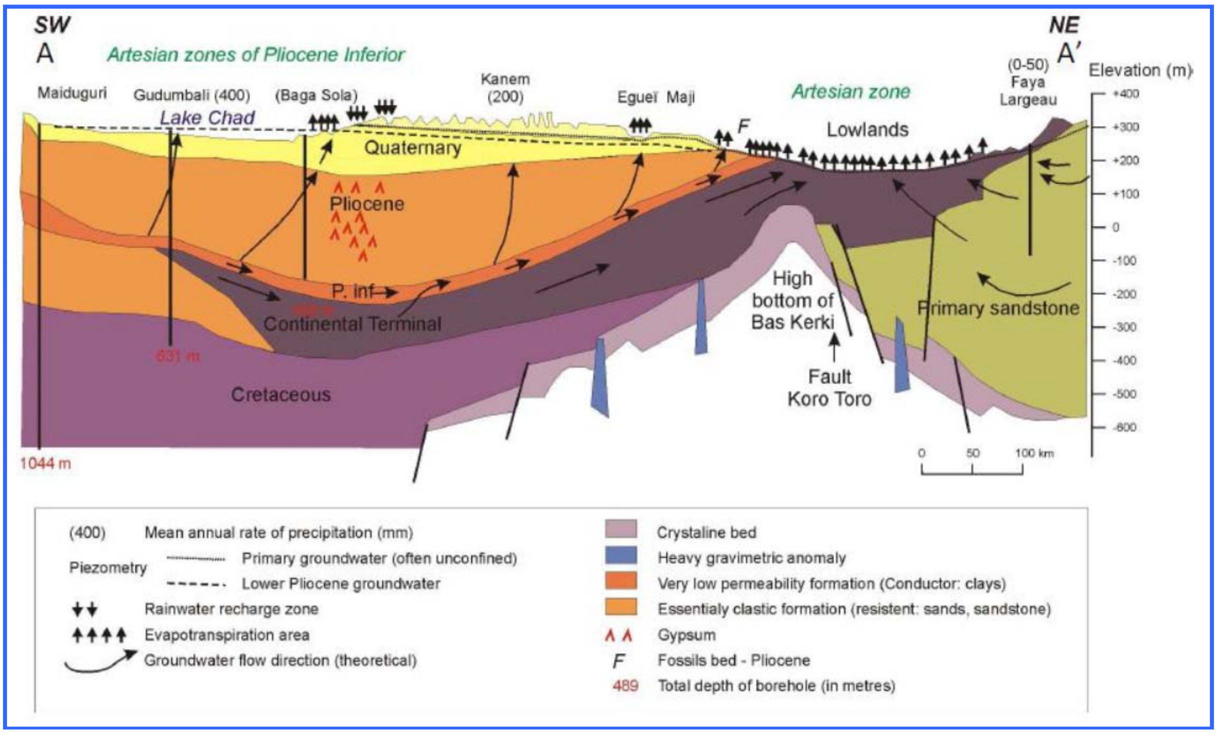


Figure 5: Cross-section (A-A', see Fig. 4) through the Chad lake Basin from Maiduguri (SW) to Faya Largeau (NE) after Schneider & Wolff, 1992 (in BRG, 2012).

At the south of the Lake, Quaternary deposits are overlaid by the Yaéré et Naga plains, where is found an alternation of sandy layers, indicator of past arid conditions, and clayey layers either lacustrine or fluvial, resulting from more humid periods when the size of the lake increased and the Logone and Chari riverbeds were much wider.

In CAF, at the very southern border of the basin, Quaternary deposits can also be found lying on the Continental Terminal deposits that crop out directly on the Proterozoic substratum.

From the hydrogeological point of view, the Continental Terminal is an artesian aquifer in the surroundings of the Lake Chad. It is outcropping in the southern part of the Basin especially in CAF where it can be also hidden by Quaternary deposits. The lower Pliocene contains freshwater and can also be artesian around the Lake Chad.

The Quaternary forms the major transboundary regional aquifer characterised by different depositional environments. The aquifers vary between semi-confined and confined depending on their relative position and the occurrence of clay layers. The Pleistocene and contemporaneous sands are characterised by relatively good hydraulic conductivity and groundwater of drinking quality. TDS is generally low (<400 mg/l), in the absence of anthropogenic influence. Few data regarding transmissivity of the aquifers in the area are available, they all show good aquifer potential with transmissivities ranging from 1.10^{-2} to 7.10^{-2} m^2/s (Schneider and Wolff, 1992). This was confirmed by Massuel (2001) with values of 2.10^{-2} m^2/s for the sand of the Pleistocene.

Most of the Lake Chad Basin is covered by Quaternary sands (Fig. 4) of different depositional origins. In the northern part of the basin prevails aeolian deposition with the presence of dunes (Kanem region). Fluviatile, lacustrine and deltaic depositions that result in alternating sequences of thin layers of sand and clay and mainly clayey soils on the surface are typical in the south. Regionally, these Quaternary sands act as an unconfined transboundary aquifer with flow direction towards the Lake Chad and the NE along the Bahr el Ghazal. South of the 14°N parallel this aquifer shows a low hydraulic conductivity, especially vertical, due to the sequences of sand and clay. Furthermore, due to its flatness and low gradient (in average 0.5‰), the horizontal flow is very slow (BGR, 2009).

At a depth of some 75 to 100 m appears a thick layer of some 280 m of clay from the Upper Pliocene age (Fig. 5). This layer separates the Quaternary sands above from the Lower Pliocene below. The Lower Pliocene is composed of sand and sandstone and has a thickness of 30 m, underlain by the sandstones of the Continental Terminal (Tertiary) with a thickness of some 150 m.

The Upper Pliocene is almost impermeable and builds thus an aquitard that confines the sandstones of the Lower Pliocene and Continental Terminal (CT) from the upper Quaternary aquifer causing widespread artesian conditions in the central part of the basin. According to Eberschweiler (1993), both transboundary aquifers the Pliocene and the CT have similar good hydrogeological properties and comparable water chemistry, therefore they can be considered as a single aquifer.

The Quaternary aquifer groundwater flow map (Fig. 6) shows the presence of three important piezometric depressions: Chari-Baguirmi, Komadougou-Yobé and Pays-Bas. To the South of the basin, groundwater flow is oriented from the South to the North in direction of Lake Chad and Chari-Baguirmi depression. To the North, the Pays-Bas depression acts as a final collector of groundwater flowing from the east (Chad) and west (Niger). Groundwater flow for the Lower Pliocene and the Continental Terminal is less documented and sparse information is only available for the region around the Lake Chad (BGR, 2009).

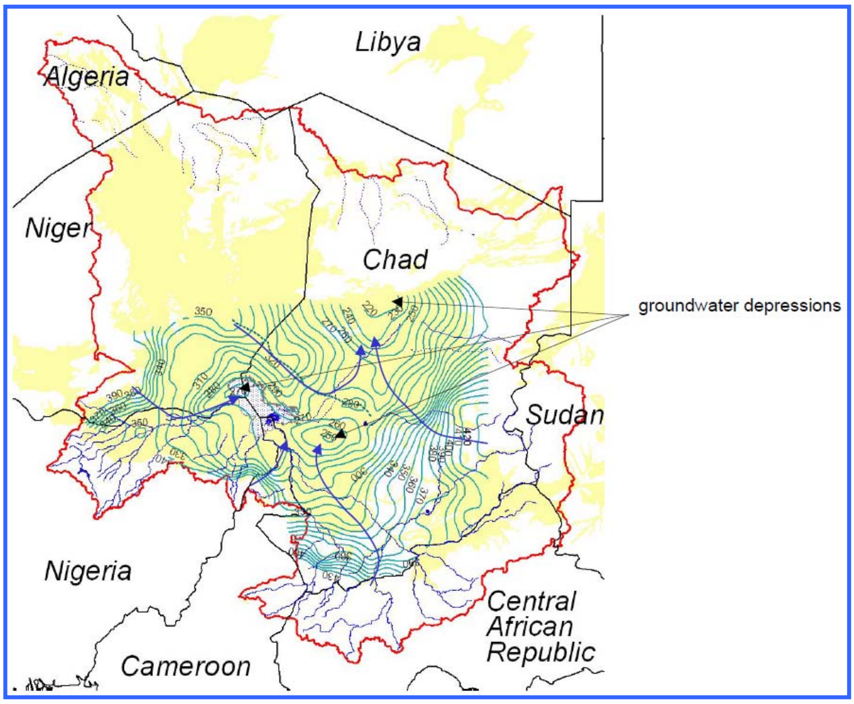


Figure 6: Potentiometric map of the Quaternary aquifer (BGR (2009).

For the Lower Pliocene aquifer, groundwater flow is also oriented globally from West to East and from South to North in the direction of Lake Chad. No piezometric information is available for the Eastern Chad region for this aquifer (Fig.7).

Groundwater flow in the Continental Terminal aquifer is organized from South to North in the direction of Lake Chad and then to the North-East of the Lake (Fig.8). Very few information is available up to now on this aquifer and this potentiometric map must be considered as schematic. Recent investigations based on ^{36}Cl by Bouchez (2015) have evaluated the residence time of the CT groundwater east of the Lake Chad to more than 300,000 years.

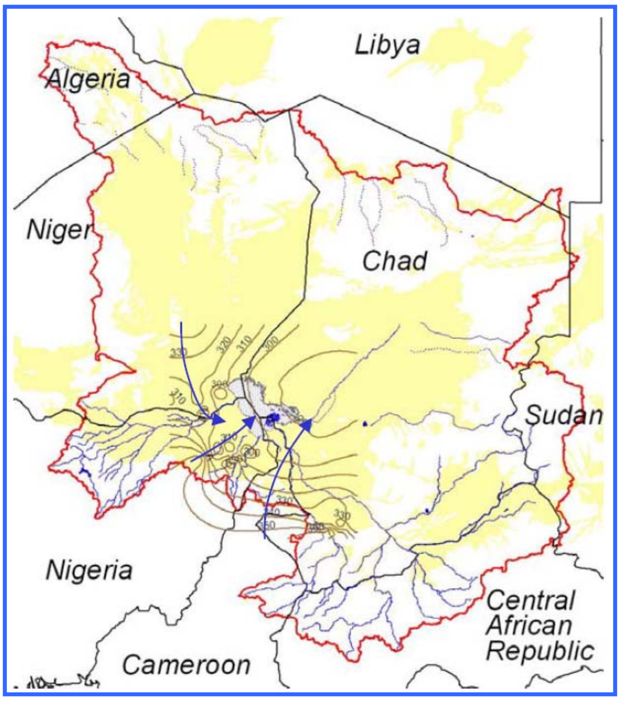


Figure 7: Groundwater contour line for the Lower Pliocene (BGR, 2009).

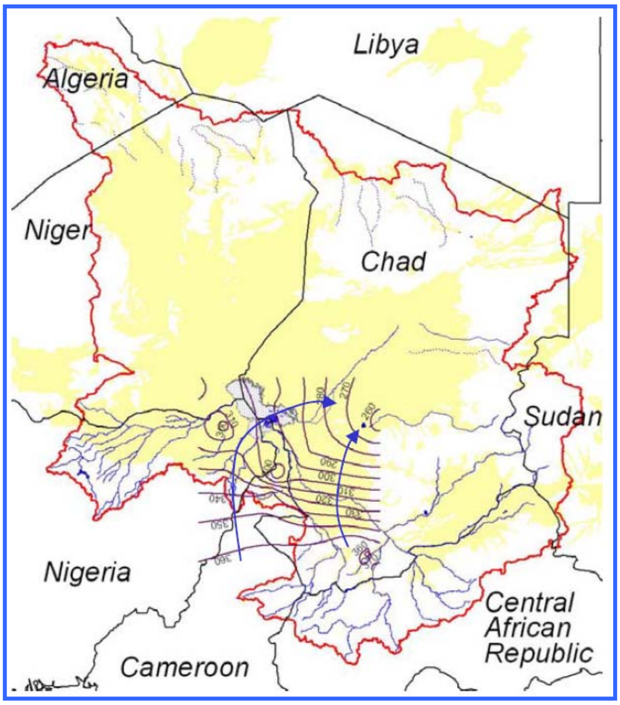


Figure 8: Groundwater contour lines for the Continental Terminal aquifer (BGR, 2009).

2.4. Hydrology

The Lake Chad Basin can be subdivided into two main hydrological sub basins:

- The Chari-Logone subsystem, which covers approximately 650,000 km^2 and hosts the Chari River and the Waza-Logone floodplains. It brings about 95% of the annual volume of water reaching the lake

- The Komadugu-Yobe subsystem, which covers 148,000 km^2 but contributes only to about 3% of the total riverine inflow into Lake Chad.

Precipitation, on the Lake Chad surface, account for about 2% of the annual volume of water, that reaches the hydrosystem. Within the basin several very important swamp regions are identified, as the Grand Yaéré in Extreme north of Cameroon (Ketchemen, 1992), Lake Chad, Lake Fiti, Massénya and Salamat to the south-east, and Komadougou-Yobé to the North-east of Nigeria (Fig. 9). Because of its shallowness (the deepest point is at 4 m) most of the Lake Chad area in the southern pond and the whole of the northern pond can be considered as a swamp (BGR, 2012).

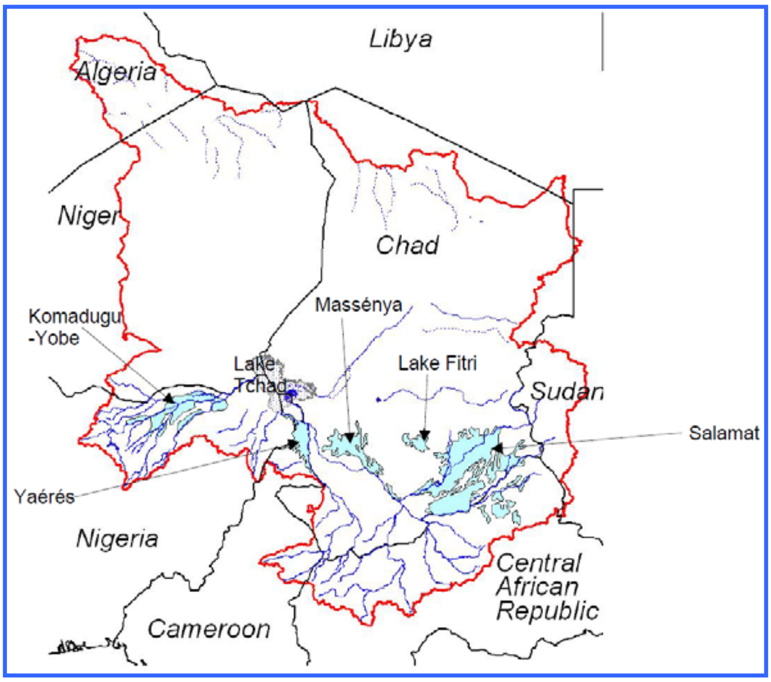


Figure 9: Swamp areas within the Lake Chad basin (BGR, 2009)

The main hydrological feature of the region remains the Lake Chad itself as the final collector of all surface and probably part of the shallow groundwater of the region. Depending on the alternation of wet and dry phases, Lake Chad has stretched or retreated many times in the past, but from 4,000 BC to date, the lake water has shrunk continuously, corresponding with the development of aridity and desert encroachment with several origins (CBLT, 2008).

Variations in Lake Chad, as shown on Fig. 10 for recent times, indicate that many changes occurred on the following landmark dates (CBLT, 2008):

- 50 000 B.P: the lake covered 2 million square kilometres;

- 20 000 B.P: it disappeared completely due to the aridity of the tropics following the peak of glaciation;
- 9 500 B.P: the Lake was enlarged by abundant rainfall on the Tibesti massif, to a depth of 15 m, before returning to the situation of around 9 000 B.P.;
- 7 000 B.P., it has a depth of 38 m, before returning to the current situation around 5500 B.C.;
- 4 000 B.P., it has a depth of 65 m, and eventually covers an area of over one million km^2, or several hundred times its current size before returning to the current situation around 2 000 B.P.;
- 2 000 B.P., the lake was then a genuine inland sea of Central Africa, which has desiccated and whose basin has filled up with sand;
- 1 000 B.P., it has a depth of 17 m, before falling back to the current situation
- 1908, the lake was merely a wetland with two small basins to the north and south, and then its level increases;
- 1963 the Lake covers, according to sources, 22 903 to 25 000 km^2;
- 2001, its surface area shrinks to 4 000 km^2;
- 2008, its dimensions are 30 by 40 km at the mouth of the Chari River with a surface area of 2500 km^2. Lake Chad covers less than 10% of the area it occupied in 1960.

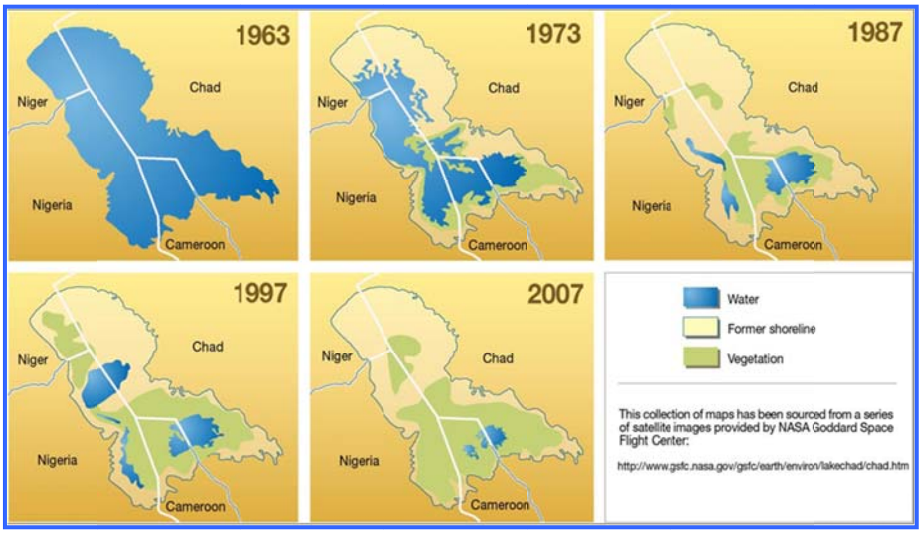


Figure 10: Lake Chad evolution since the 1960's (From NASA in CBLT, 2008).

The Logone-Chari hydrological system which is the main contributor to the Chad Lake hydro-system is flowing from the south of the basin towards the central part. The Chari River and its major tributary, the Logone are both originating from Northern Cameroon and North-western Central African Republic, which are located in the Sudanese-Guinean part of the basin with important rainfall amounts. Logone and Chari Rivers are joining slightly south of N'Djamena city before Chari River reaches Lake Chad.

Figure 11 illustrates the yearly evolution of the mean monthly discharge of the Chari after its mixing with the Logone River. High water are observed from September to November and low water are observed in April and Mai. A delay of about 2-3 months can be observed at N'Djamena between the peak in rainfall amount of the rainy season in August and the flood of the Chari in October.

N'Djamena airport weather station used to be part of the GNIP network from 1963 to 1995, but the records stopped for 20 years before being reactivated in 2015 in the framework of the IAEA-supported project RAF/7/011. At the same time and in the same framework, a new GNIR station was deployed on the Chari River at “Travaux Publics” (TP) hydrometric station at the North N'Djamena city. Both stations are now managed by the staff of the “Ministère de l'Elevage et de l'Hydraulique” of the Chad Republic.

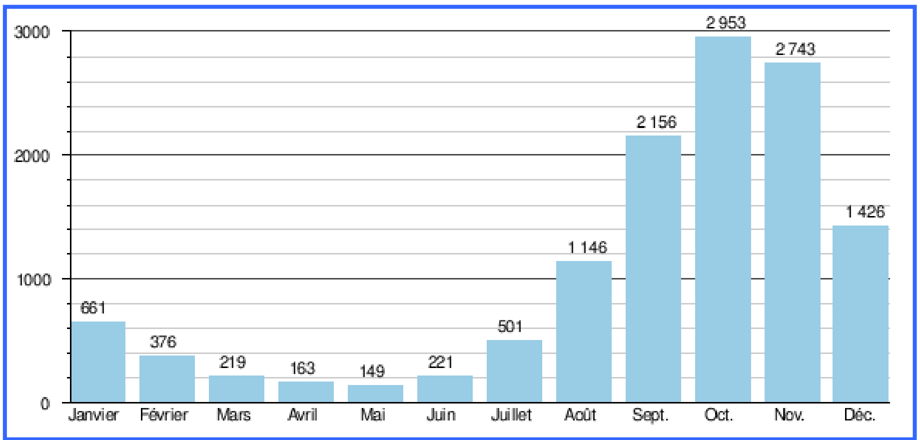


Figure 11: Mean monthly discharge in m^3/s of the Chari River at N'Djamena TP hydrological station (1933-1991).

Figure 12 displays the $\delta^{18}O/\delta^2H$ correlation in N'Djamena rainfall (1964-1995). From this dataset (Table 4), a Local Meteoric Water Line (LMWL) is proposed: $\delta^2H = 6.3 \times \delta^{18}O + 4.3$.

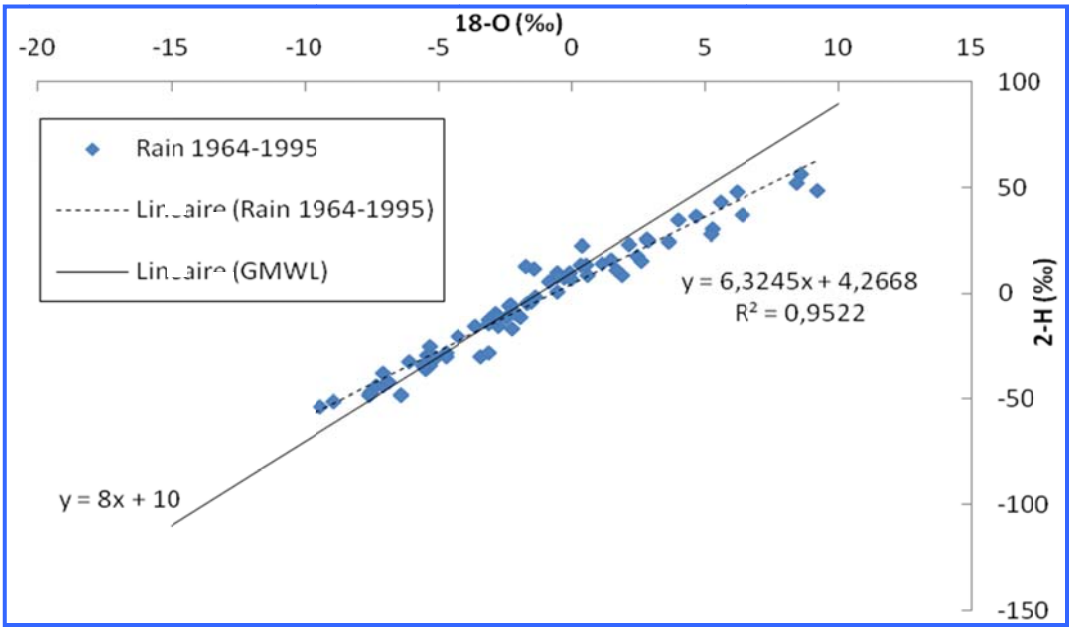


Figure 12: $\delta^{18}O/\delta^{2}H$ diagram for monthly data of the N'djamena GNIP station (1964-1995)

Table 4: Local meteoric water line statistics according to WISER GNIP data.

Regression Type	a	b	Standard Error	R²	N
LSR	6.32 ±0.16	4.27 ±0.76	6.18	0.95	73
RMA	6.48 ±0.17	4.47 ±0.75	6.18	0.95	73
PWLSR	6.34 ±0.16	3.84 ±0.80	4.73	0.96	73

Tritium in N'Djamena precipitation has also been surveyed in a very discontinuous way (Fig. 13) from 1963 to 1978. The N'Djamena GNIP station is the only one over the watershed area.

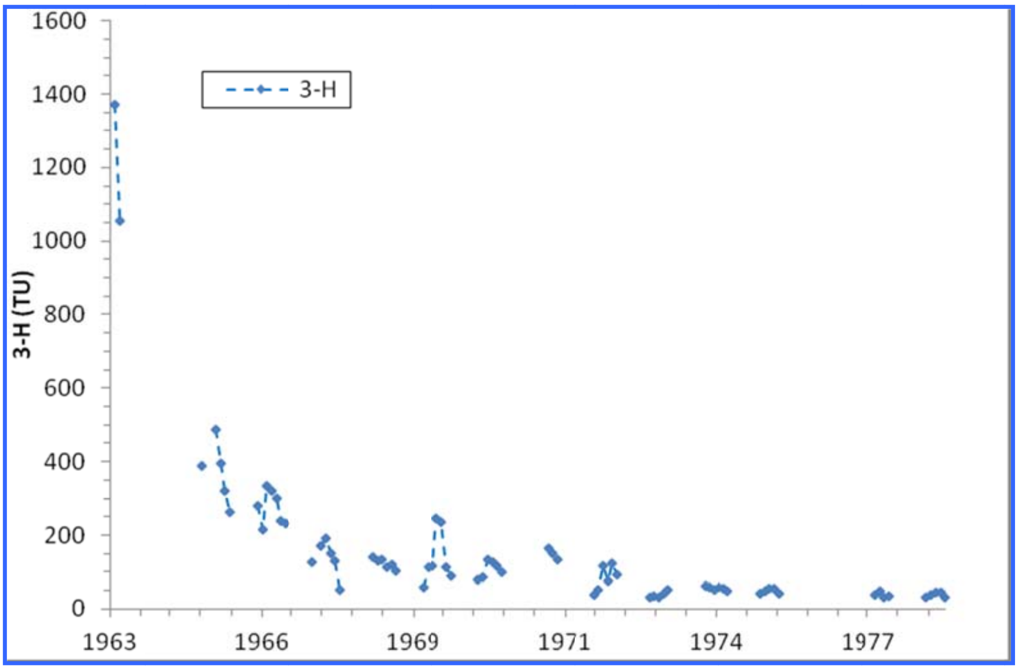


Figure 13: Evolution of ^{3}H in rainfall of the N'djamena GNIP station (1963-1978)

2.5. Vegetation types, Land use

The vegetation of the Chad Lake basin is much contrasted from the dry North to the tropical South. It is broadly categorized under the three regions of the northern Sahara zone, the central Sahel zone, and the southern Sudan zone. The northern part of the basin which has the Sahara desert and which borders Libya and the volcanic massif of Tibesti (3415 metres) forms part of the northern zone. Vegetation is dominantly tropical in the southern zone. However, a large area of the basin is made of desert dunes where fringes of xerophytic scrubland are noted. The transition zone that lies between the southern Sahel and northern Sudan–Guinea is a major seasonal wetland. The Sudan Savanna zone mostly consists of Sudanese woodland with intermittent vegetation of edaphic grassland and acacia.

Lake Chad zone is one of the richest areas of flora of the basin, although it has rapidly reduced in size during the last century. The well-drained soils of the area once supported areas of dense woodlands with ebony and kapok trees, but this has declined due to soil erosion and degradation. Vegetation found in the area includes acacias, baobab, desert date, palms, African myrrh, and Indian jujube.

Agriculture is the main activity in the region, mostly rain-fed in the south or recessional in the flooded areas. However, there is cash-crop irrigation (mostly rice and cotton) along the river courses. Between 1983 and 1994, demand for irrigation grew by 200% leading to overexploitation of the water resources which were already under stress due to severe droughts (UNDP, 2006). Groundwater irrigation is increasing in areas where precipitation is irregular (marginal lands), which is of concern due to the low irrigation efficiency.

2.6. Water supply and water resources management in the basin

The 47 million people living in the Lake Chad Basin belong to some of the poorest countries of the world. According to the UNDP ranking of human development, out of the 177 countries listed, Cameroon occupies the position 144, Nigeria the 159, Chad the 171, CAR the 172 and Niger the 177. The rural settlements show even larger poverty levels than the already high national averages.

Access to safe drinking water is low ranging from 26% in Chad to 56% of the population of Niger in 2000, according to UNDP. In rural areas, most of the water users obtain water

directly from ponds during the rainy season or from hand dug wells in the dry period. Groundwater is the major resource for central water supply in the cities, but connection is not widespread due especially to the costs that cannot be afforded by a large part of population.
The sanitary conditions are very poor in all countries. Water prone infections like hepatitis, typhus and cholera are widespread. Malaria is endemic in the entire basin, except in the northern countries (Libya and Algeria).

To improve water management at the scale of the whole basin and in a transnational way, the Lake Chad Basin commission was created in 1964. The mandate of the Commission is to sustainably and equitably manage the Lake Chad and other shared water resources of the Lake Chad Basin, to preserve the ecosystems of the Lake Chad Conventional Basin, to promote regional integration, peace and security across the Basin.

In 2009, the Council of Ministers of the Lake Chad Basin Commission adopted the UN draft resolutions for transboundary aquifers as a basic document to rely on in groundwater management (BGR, 2012). The Lake Chad Basin Commission is in the process of adoption of a Water Charter for the basin that will regulate the shared management of water resources and ecosystems. Although surface water is the main issue, groundwater has its place. For each member state a maximum of river water that can be extracted at predetermined reference points has been set based on an "ecological discharge", that means "the minimum amount of flow to maintain good ecological conditions for the associated ecosystems" (LCBC, 2011). The countries must negotiate to determine the volume of water that each of them will be allowed to extract, if the ecological discharge is to be obtained (BGR, 2012).

Despite the existence of a legal basis, groundwater management is not yet a major problem in the basin, due perhaps to the advisory role of the Lake Chad Basin Commission (BRG, 2012). All member states decide on large investments and construction projects (dams, deep wells) without due consideration for the possible effects on neighbour countries. International donors finance these large projects under the condition of a non-objection from the LCBC (BGR, 2012).

Through the Water Charter, which must be signed and adopted by the member states, the LCBC will have a modern tool for transboundary water governance. While transboundary surface water has been extensively studied since the establishment of the LCBC, the knowledge of transboundary groundwater is very poor. When it comes to groundwater, only four transboundary projects can be listed since the creation of the LCBC (BGR, 2012):

- FAO project finished in 1973 that investigated for the first time the transboundary groundwater in the area through an extensive drilling programme, among others.

- BRGM project finished in 1993 (Eberschweiler, 1993) that set the first regional groundwater model including the Quaternary sands, Lower Pliocene and Continental Terminal.

- UNESCO project finished in 2003 that investigated the Chari-Logone region between Chad and Cameroon.

- BGR projects, which have studied mainly the Quaternary groundwater in the Chadian part of the basin but intends to prolong the investigations towards Cameroon, Nigeria and Niger.

3. DATA ACQUISITION AND METHODOLOGY USED

In the framework of the IAEA-supported project RAF/7/011, field activities have been carried out in Chad, Niger, Cameroon and Central African Republic. Different regions have been investigated as shown in Fig. 14:

- Ouham (around Batangafo) and Ouham-Pendé (around Bossangoa) provinces of the Central African Republic,
- Grand Yaéré in the Extreme North of Cameroon,
- Diffa region in Niger,
- Central Chad

Major problems in terms of access to the field and main concerns about security for the technical staff in charge of the sampling activities prevented the different teams to investigate other areas of the watershed.

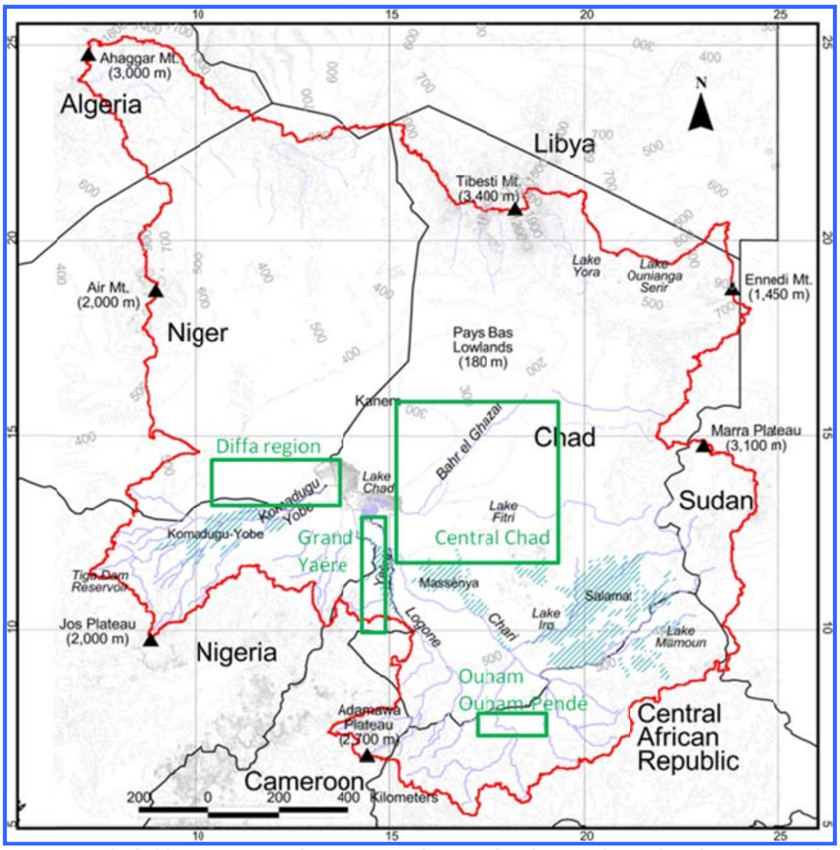


Figure 14: Location of different study areas through the Lake Chad Basin where field work and sampling was carried out during the implementation of the IAEA-supported project RAF/7/011.

The location of the different sampling points over each investigation area is displayed on Figures 15 to 18.

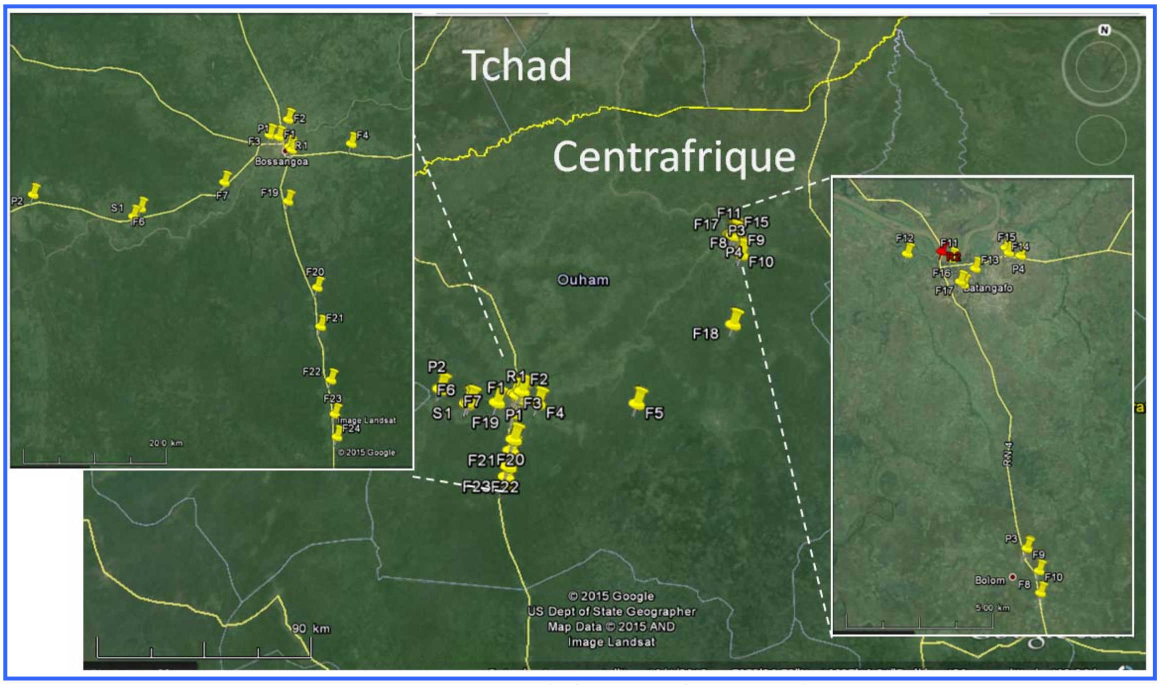


Figure 15: Location of the sampling site for CAF

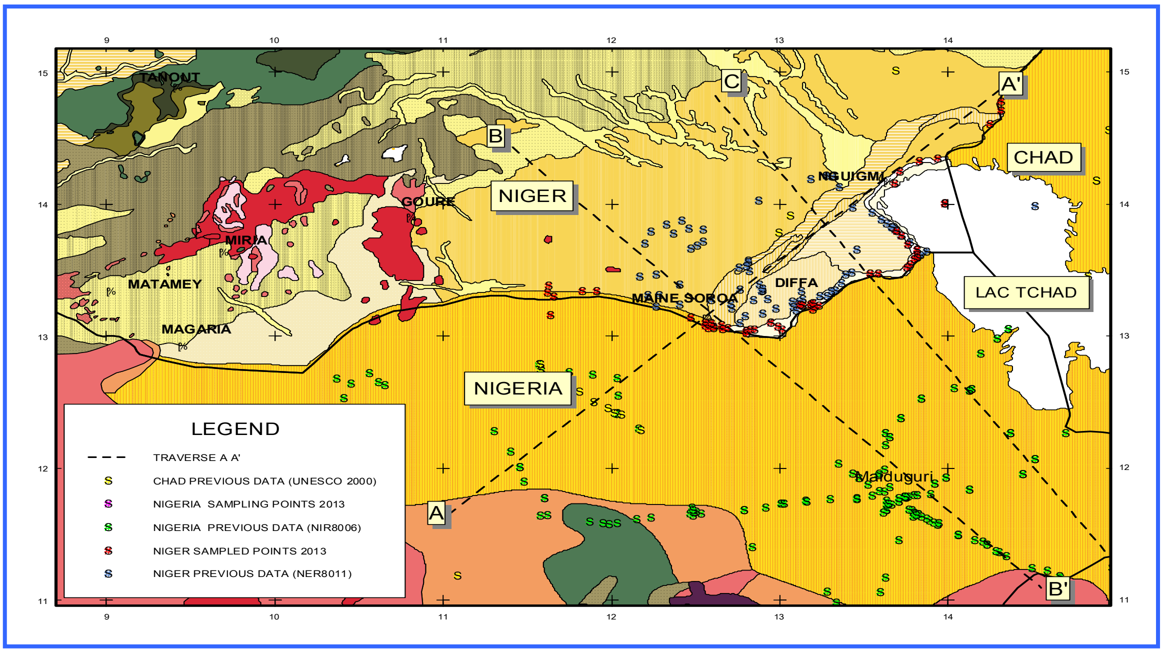


Figure 16: Location of the sampling sites for Niger (red dots)

Sampling campaigns were organised as much as possible considering the security issues of the region in two field campaigns as displayed in Table 5.

Table 5: Overview of the national field activities for each partner of the IAEA-supported project RAF/7/011 and different laboratories where samples were analysed

	Number of campaign	Sampling date	Type of analysis	Number of samples	Lab.	Aquifer
CAF	1	Aug-Nov/2014	Major ions ^{18}O- ^{2}H, ^{3}H	31 31, 0	Sfax Sfax	CT Metamorphic
CAF	2	April/2015	Major ions ^{18}O- ^{2}H ,^{3}H	30 30, 12	Sfax Sfax	CT Metamorphic
Cameroon	1	April/2013	Major ions ^{18}O- ^{2}H, ^{3}H	86 86, 0	CNESTEN CNESTEN	Quaternary Metamorphic
Niger	1	Feb/2013	Major ions ^{18}O- ^{2}H, ^{3}H	50 50, 50	Sfax Sfax	Quaternary
Chad	1	July/2013 Jan-Apr/2014	Major ions ^{18}O- ^{2}H, ^{3}H	400 (136) 120, 88	Chad IAEA/CzTU Hydrosys	Quaternary

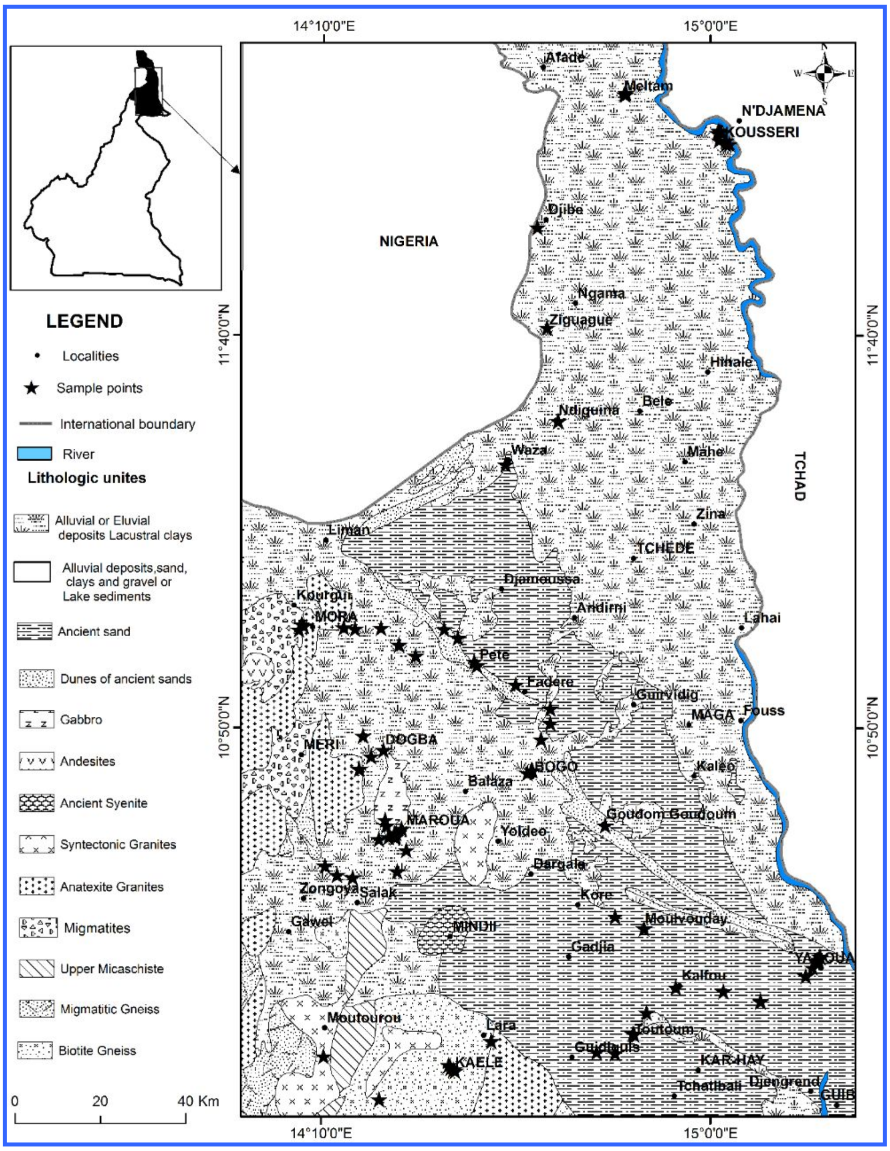
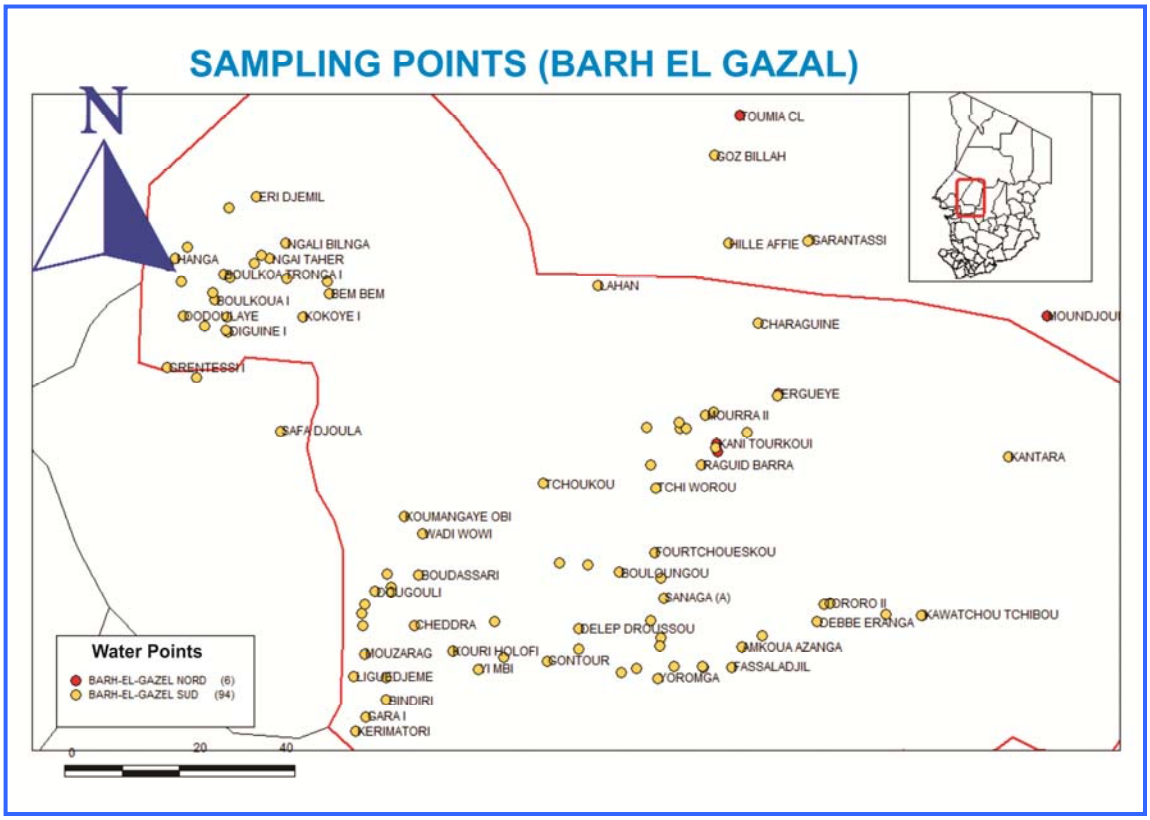
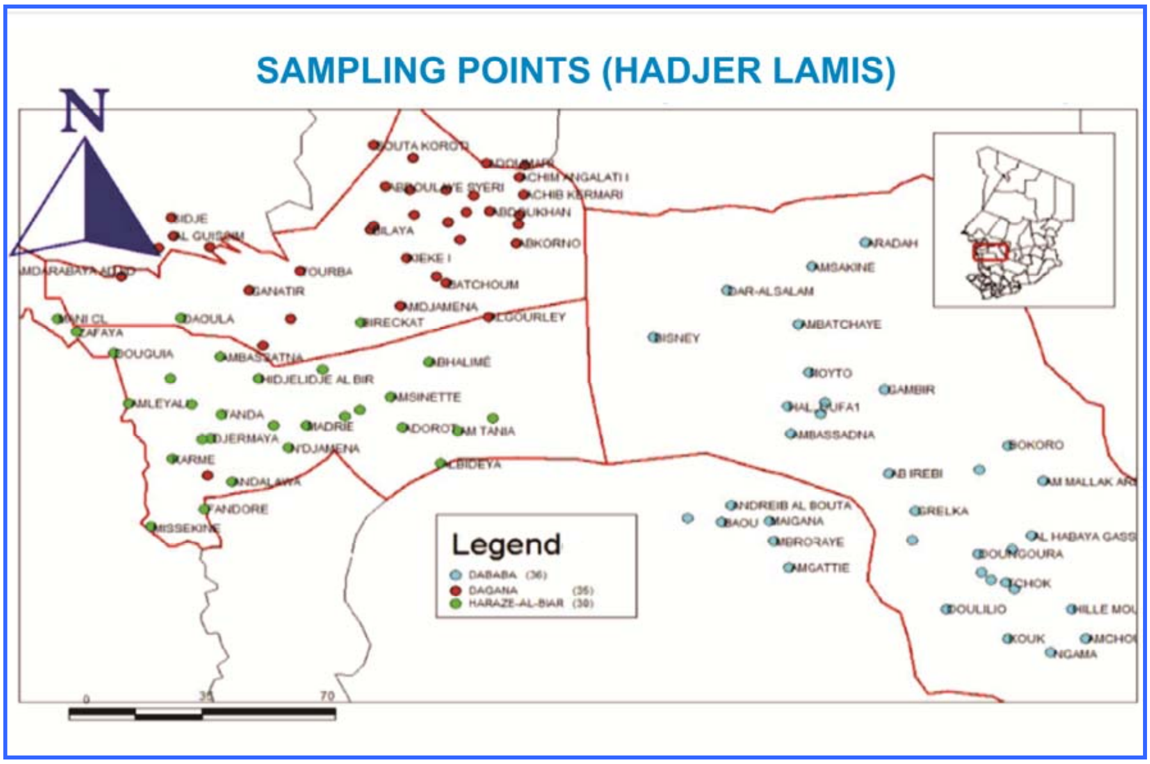


Figure 17: Location of the sampling sites for Cameroon


SAMPLING POINTS (BARH EL GAZAL)
N
TOUMIA CL
GOZ BILLAH
ERI DJEMIL
NGALI BILNGA
HANGA
NGAI TAHER
BOULKOA TRONGA I
BEM BEM
BOULKOUA I
DODOULAYE
KOKOYE I
DIGUINE I
HILLE AFFIE
GARANTASSI
LAHAN
CHARAGUINE
MOUNDJOU
GRENTESSI I
ERGUEYE
OURRA II
SAFA DJOULA
KANI TOURKOUI
RAGUID BARRA
KANTARA
TCHOUKOU
TCHI WOROU
KOUMANGAYE OBI
WADI WOWI
FOURTCHOUESKOU
BOUDASSARI
BOULOUNGOU
DOUGOULI
SANAGA (A)
DORORO II
KAWATCHOU TCHIBOU
CHEDDRA
DELEP DROUSSOU
DEBBE ERANGA
MOUZARAG
KOURI HOLOFI
AMKOUA AZANGA
YI MBI
CONTOUR
FASSALADJIL
LIGUEDJEME
YOROMGA
BINDIRI
GARA I
KERIMATORI
Water Points
BARH-EL-GAZEL NORD (6)
BARH-EL-GAZEL SUD (94)
0
20
40


SAMPLING POINTS (HADJER LAMIS)
N
KOUTA KOROTI
ABDOULAYE SYERI
ACHIM NGALATI I
ACHIB KERMARI
ABDOUKHAN
ABKORNO
GUILAYA
JEKE I
TOURBA
BATCHOUM
GANATIR
AMDJAMENA
ALGOURLEY
BIRECKAT
DAOULA
ZAFAYA
BOUGUIA
AMBASSATNA
HIDJELIDJE AL BIR
ABHALIME
AMSINETTE
AMLEYALE
TANDA
MADRIE
DJERMAYA
N'DJAMENA
ADOROT
AM TANIA
KARME
ANDALAWA
LEBIDEYA
FANDORE
MISSEKINE
ARADAH
AMSAKINE
DAR-ALSALAM
AMBATCHAYE
BISNEY
MOYTO
GAMBIR
AMBASSADNA
BOKORO
AB IREBI
AM MALLAK
ANDREIB AL BOUTA
GRELKA
BAOU
MAIGANA
MBRORAYE
AMGATTIE
BOUNGOURA
DOULILIO
KOUK
NGAMA
Legend
DABABA (36)
DAGANA (35)
HARAZE-AL-BIAR (30)
0
35
70

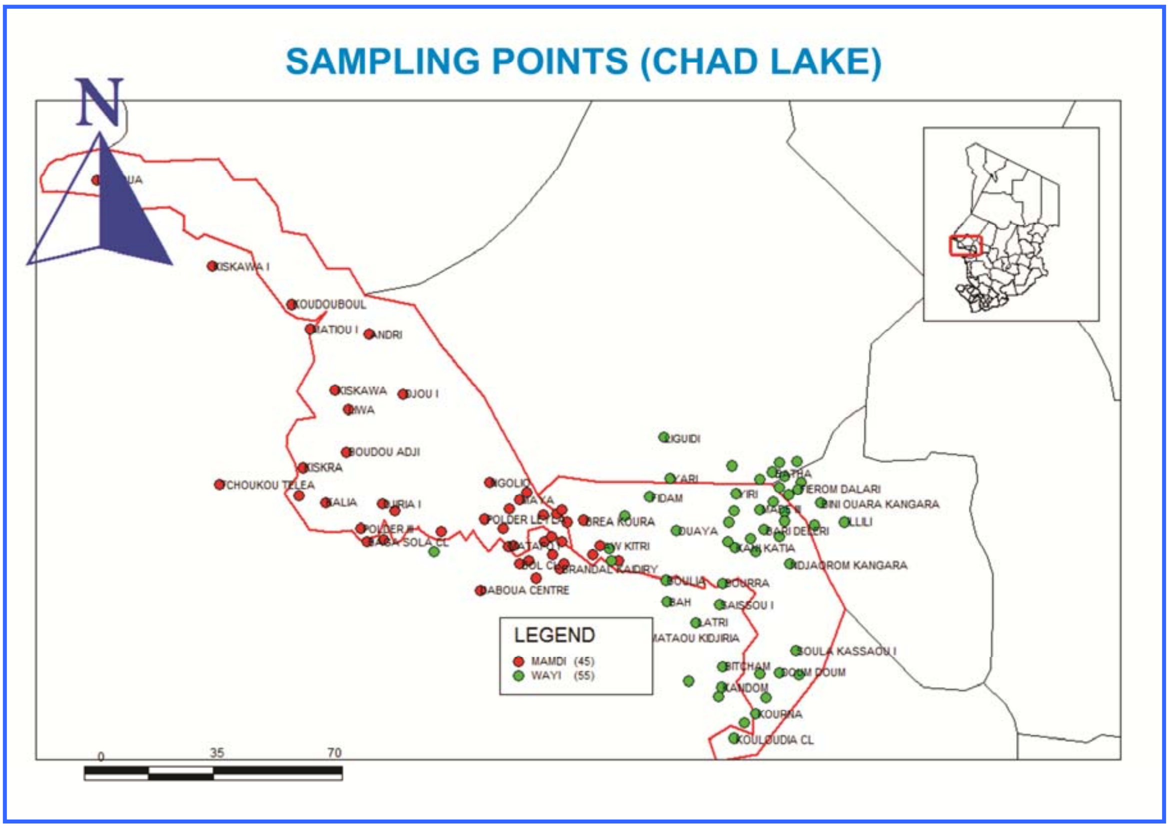


Figure 18: Location of the sampling sites for Chad

All partners faced important difficulties to organise the field activities from access to the field site because of the weather conditions, to limitation into sampling facilities and to the most worrying security issues. Hence, given the very serious difficulties only CAF managed to organise two field campaigns in the Southern part of the watershed. Chad, Niger and Cameroon were only able to organise one single sampling campaign. For each partner sampling campaigns have been organised in order to sample water for the different parameters: major ions, stable isotope of the water molecule ^{18}O and ^{2}H, tritium ^{3}H on all sample or after selection. The sampling procedures protocol developed by the IAEA has been respected by the different partners and includes the following parameters: electric conductivity (EC), temperature (T), pH, alkalinity, geographic coordinates and type of sampling point. Quality control for the geochemical analysis was insured by ionic balance calculation. For Chad data, it appeared that 66% of the analysis showed disequilibrium higher than 10% and thus were not considered in this report. Only 136 analyses were kept for the synthesis. It must also be noted that for Chad no match between the geochemical data and the isotopic data was provided to the expert for the interpretation. So the two datasets were considered independently.

4. RESULTS AND INTERPRETATION

4.1. Reactivation of the GNIP station of N'Djamena

One of the very positive accomplishments of the IAEA-supported project RAF/7/011 is the reactivation of the N'djamena GNIP station after 20 years of discontinuity. The year 2015 provides the first full record including tritium measurements for the 5 months of the rainy season. The new station in deployed in a property of the "Ministère de l'Elevage et de l'Hydraulique" very close to the former one which was standing at the International Airport. A weighted mean can be calculated for 2015 (Table 6) and is about -1.9‰, -3.5‰ and 4,4 TU respectively for δ^{18}O, δ^{2}H and ^{3}H. It is very difficult to draw any tendency from just one year of data especially if it is compared with the old record from the same station (Fig.19). So, for the moment we cannot conclude on any isotopic signature evolution on a temporal basis.

Table 6: Monthly isotopic composition of the rainfall for the new N'Djamena GNIP station

sampling date	18O (‰)	2H (‰)	d (‰)	3H (TU)	±	EC(µS/cm)	pH	H (mm)
15/06/2015	2,26	13,33	-4,75	2,70	0,20	13,3	5,47	81,2
15/07/2015	-1,78	-3,65	10,59	4,50	0,30	37,9	6,62	235,7
15/08/2015	-4,13	-22,59	10,45	5,10	0,40	19,6	7,14	162
15/09/2015	-1,94	-3,82	11,7	4,70	0,40	26,3	7,74	81,9
15/10/2015	2,55	23,62	3,22	4,04	0,14	51	7,1	1,1

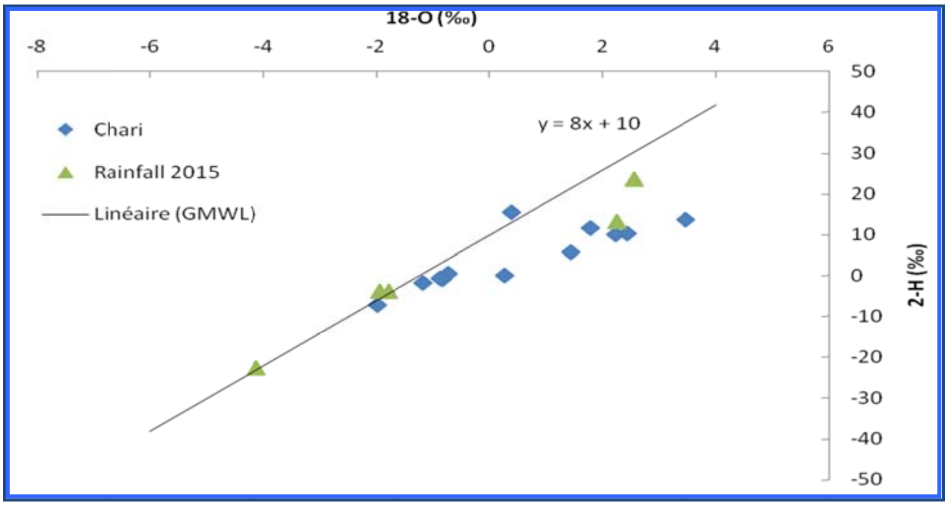


Figure 19: δ^{18}O vs δ^{2}H diagram for the 2015 monthly rainfall data of the new N'djamena GNIP station and the 2015 monthly sampled River water of the Chari.

2015 provided relatively enriched values in δ^{18}O and δ^{2}H contents if compared to the former records but this phenomenon seems to be more related to a regional tendency (especially if we have a look to the closest GNIP station of Bangui (Central African Republic) which is lying in a different climate context). 2015 was a quite rainy year (562 mm) for N'djamena and thus a longer record is needed to be able to draw any robust tendencies from it.

4.2. Deployment of the new N'Djamena GNIR station

Another accomplishment of the IAEA-supported project RAF/7/011 was the installation of a new GNIR station on the Chari River at the gauging station of Travaux Publics (TP) North of the city after the confluence of both Chari River and Logone River. The record began in January 2015 and includes tritium measurements in the river water in addition to $\delta^{18}O$ and $\delta^{2}H$ (Fig. 20).

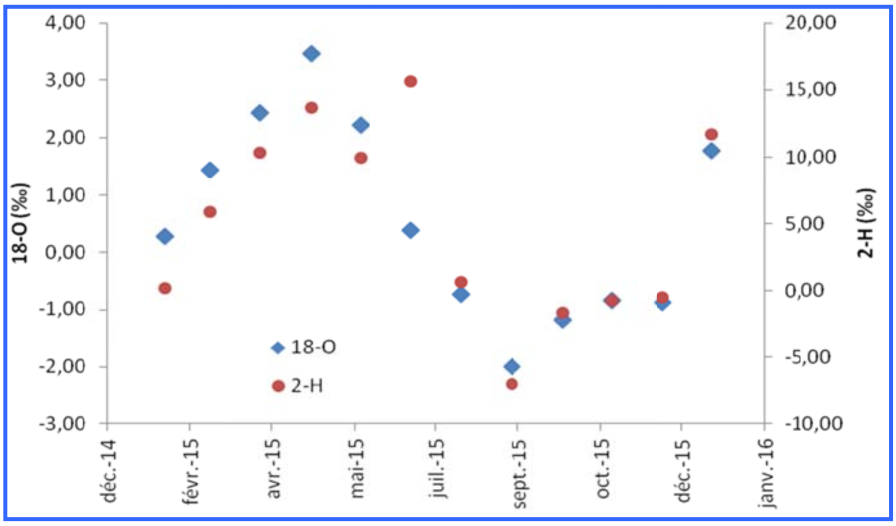


Fig. 20: ^{18}O and ^{2}H in the Chari River water at N'Djamena TP gauging station for 2015.

The isotope data show a strong seasonal evolution with strongly enriched values for April-May corresponding to the low water period, and strongly depleted values for September-October-November corresponding to the high water period. From December to May, the River water shows a clear tendency towards evaporation. The tritium activity in river water is roughly comprised between 3 and 5 TU, which is relatively important, with a tendency towards higher values for the post rainy season period prolonged by the high water period (Fig.21).

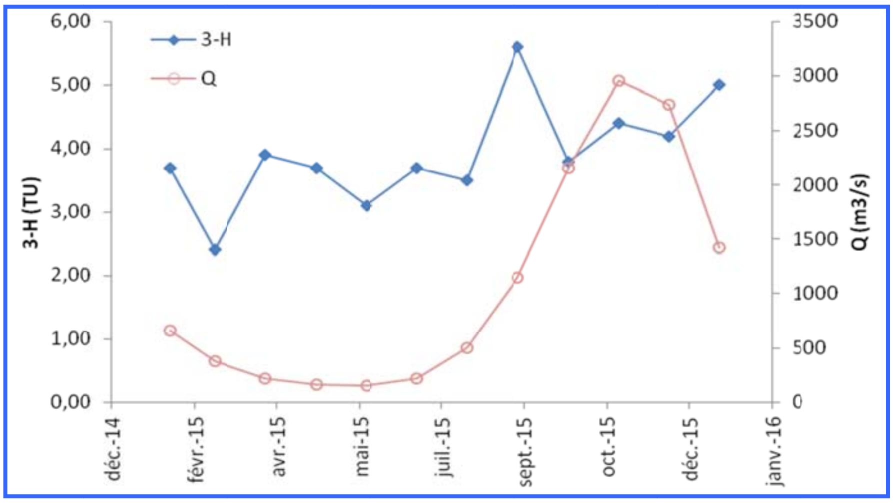


Figure 21: ^{3}H in the Chari River water in relation with the average monthly discharge at N'Djamena TP gauging station for 2015.

4.3. Hydrogeochemistry of groundwater

As previously mentioned most samples concern groundwater from the shallow quaternary aquifer sampled throughout the Chad Lake basin. A few samples are from basement crystalline rocks both granitic and metamorphic essentially in the CAF and Cameroon.

Geochemical signature of groundwater

-Physico-chemical parameters

Considering the vast area covered by the samplings and the contrasted hydrogeological conditions encountered for the Quaternary aquifer in terms of recharge conditions and surface water/groundwater interactions, the physico-chemical parameters reflect a quite large variability of EC, T and pH (Table 7). The most relevant parameters for comparison are probably the EC which shows quite high values for the Central Chad basin area in Chad, Niger and Northern Cameroon. A large variability is also observed between samples with low EC taken from humid areas (basically connected to surface water) and clearly arid contexts displaying high EC values. This was also observed by BGR (2009) in the southern Chad region (Chari and Massénya swamp areas). CAR lies apart from this tendency with relatively low EC linked to the very surficial character of the groundwater sampled and due to the more favourable humidity conditions of the country. pH values are very close to neutral figures for the Central Chad and Niger located in the very heart of the sedimentary basin to more acidic groundwater for samples taken from CAF and Northern Cameroon, both sectors being hydraulically connected to substratum crystalline aquifers and clearly influenced by mixing with low mineralised hard rock groundwater. Temperature of groundwater in most cases evolves between 26 and 38 degrees reflecting the average atmospheric temperature conditions in the region and for the shallowest samples the temperature of the sampling conditions (Fig.22).

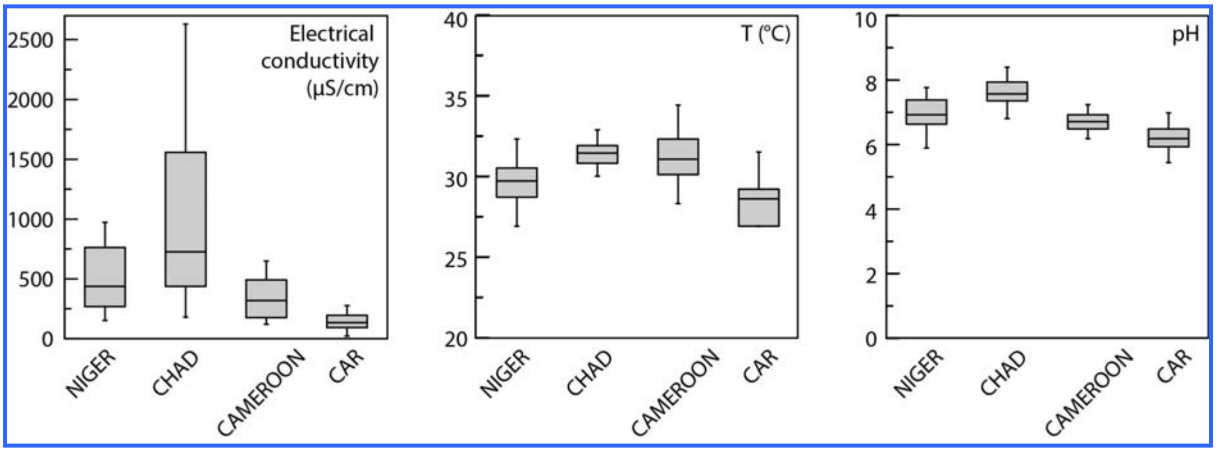


Fig. 22: Box plots showing the main physico-chemical parameters for the Chad Lake Basin.

Table 7: Summary of the main physico-chemical characteristics of Quaternary groundwater

	pH	EC (µS/cm)	T (°C°)
CHAD	Min : 5.2 Max : 9.5 Mean : 7.3 σ : 0.6	Min : 105.0 Max : 8250.0 Mean : 1355.1 σ :1526.9	Min : 28.4 Max : 33.5 Mean : 30.9 σ :1.1
NIGER	Min : 2.3 Max : 8.5 Mean : 6.9 σ : 1.1	Min : 149.8 Max : 4510.0 Mean : 834.4 σ :1064.4	Min : 26.9 Max : 38.3 Mean : 29.7 σ :2.2
CAMEROON	Min : 5.3 Max : 7.4 Mean : 6.7 σ :0.4	Min : 16.6 Max : 3600.0 Mean : 547.7 σ :647.0	Min : 26.0 Max : 34.6 Mean : 31.2 σ :1.5
CAR	Min : 5.1 Max : 8.0 Mean : 6.3 σ :0.6	Min : 21.9 Max : 601.0 Mean : 168.4 σ :119.8	Min : 20.6 Max : 31.5 Mean : 27.2 σ :3.1

- Groundwater types through the Lake Chad Basin

For the four different sectors of Chad no clear relation between the water type and the mineralisation intensity can be observed. Water types are intermediate between HCO_3^--Na^+-K^+ and Cl^--Na^+-K^+ (Fig. 23). Strong evaporation conditions and water/rock interactions are both responsible for the geochemical signature of the groundwater. These two water types are characteristic of this area and have also been observed and described by previous authors on the area, the latest being the BGR (2009). The HCO_3^--Ca^{2+} water type is not broadly observed which is expected considering the lack of surface water in this area and the very limited fast exchanges between surface and underground.

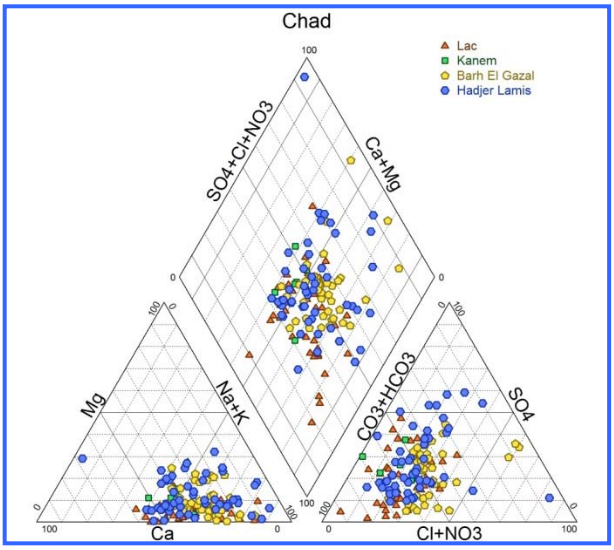


Figure 23: Piper diagram for the groundwaters of the Quaternary aquifer in Central Chad

South-eastern Niger groundwater samples, like Chadian samples, do not display a clear dominant geochemical signature (Fig. 24). Some evolution can be observed along the sampling flow line from HCO_3^--Ca^{2+} to HCO_3^--Na^+-K^+ and then to Cl^--Na^+-K^+ water types. This evolution is also linked to a clear increase in the EC of groundwater showing a stronger influence of both evaporation and residence time (through the water/rock interactions intensity) along the flow towards the central Lake Chad basin. The HCO_3^--Ca^{2+} water type is encountered near surface water courses where exchanges with shallow groundwater can take place.

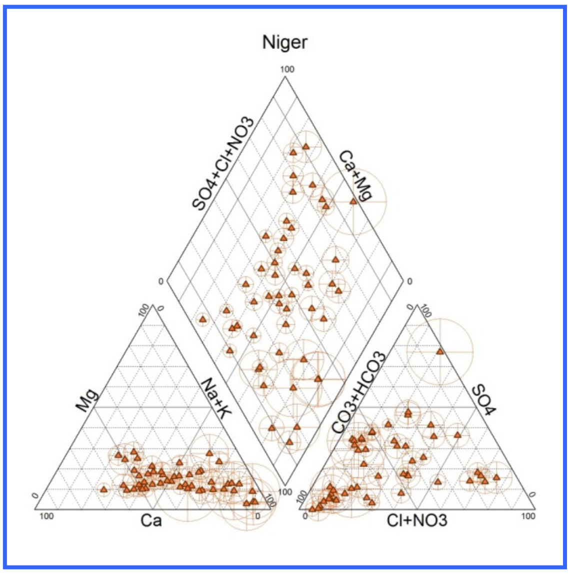


Figure 24: Piper diagram for the groundwaters of the Quaternary aquifer in the south-eastern part of Niger (the circles around the points are proportional to the EC)

Groundwater from Northern Cameroon (Fig. 25) are mostly of HCO_3^--Ca^{2+} type and this is especially the case for the shallow groundwater of the Quaternary aquifer which are in close relation with the surface water of the Logone and Chari rivers right before their confluence and discharge into the Lake Chad. Groundwater from the crystalline basement are more spread over the entire Piper diagram showing a tendency to the HCO_3^--Na^+-K^+ water type in relation with water/rock interaction with silicate minerals and to the Cl^--NO_3^--Ca^{2+} water type clearly in relation with a strong anthropogenic influence on groundwater and particularly high nitrate concentrations near sampling points as is often observed in Africa (Travi and Mudry, 1997 ; Huneau et al., 2011 ; Rajkumar and Xu, 2011 ; Djebebe et *al.,* 2013).

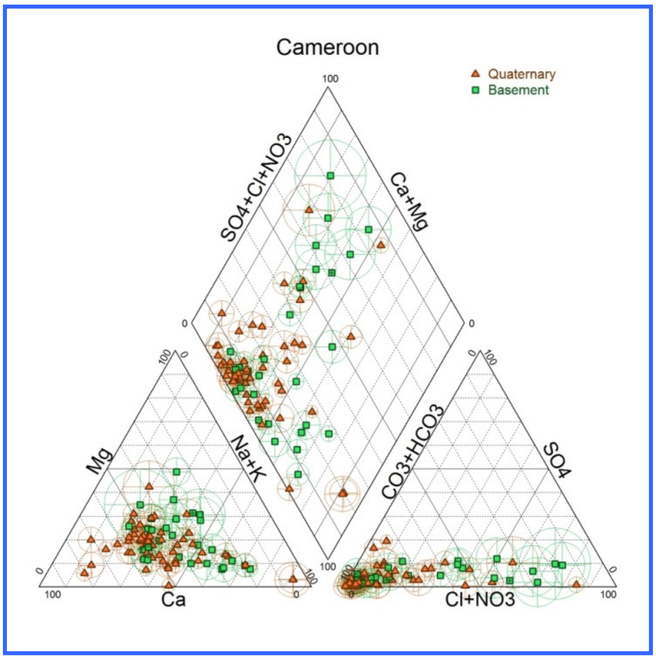


Fig. 25: Piper Diagram for the Quaternary and basement aquifer groundwater of Northern Cameroon (the circles around the points are proportional to the EC)

The 2014 campaign took place before the rainy season and the 2015 after the rainy season.
Groundwater from Northern CAF are mostly of HCO_3^--Ca^{2+} type showing their specificity in terms of origin (head of the watershed) and probably very short residence time in a relatively humid region of the Chad Lake Basin.

-Major ion distribution in groundwater

A first illustration of major ions concentrations is been displayed below on simplified boxplots (Fig. 26) in order to evacuate the chaotic aspects of the dataset strongly influenced by extreme values.

Major ions distribution is controlled by both the intensity of evaporation processes and the intensity of the water-rock interaction processes, which is related to the residence time of groundwater. A very strong anthropogenic influence is also observed for a large amount of groundwater samples from this study and can be considered as an important phenomenon.

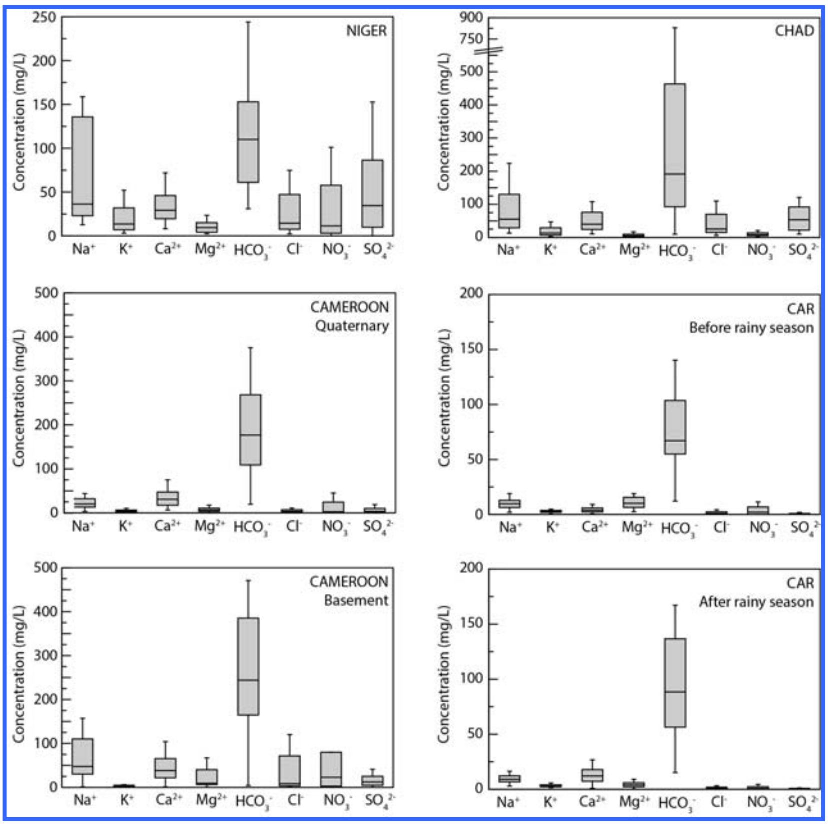


Figure 26: Simplified boxplots of the major ions for the Chad Lake Basin.

-Evaporation and water-rock interaction controlling groundwater chemistry

Groundwater samples from Chad (Fig. 27) clearly illustrate the major influence of Na^+ and Cl^- on groundwater mineralisation in the area. These ions clearly show the action of strong evaporation conditions on surface and shallow groundwater and the formation of evaporitic rocks over the entire Lake Chad basin area. Evaporation concentrate mineral species in water but in a second step the evaporitic rocks previously formed can dissolve and contaminate shallow groundwater during the infiltration processes to the aquifer.

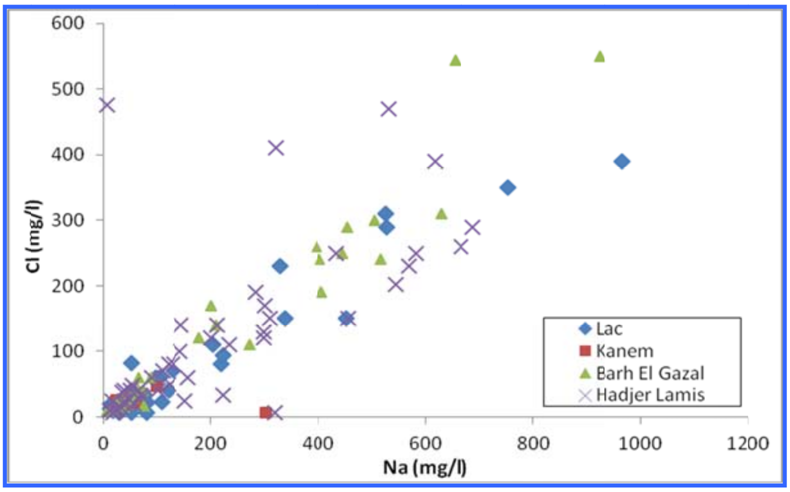


Figure 27: Na^{+} vs Cl^{-} in groundwaters of the Quaternary aquifer in Chad

-Surface water control on groundwater geochemistry

For the most humid zones of the Lake Chad Basin, like Northern Cameroon (Fig. 28) and Northern CAR, groundwater chemistry is dominated by Ca^{2+} and HCO_3^- as a result of interactions with the Quaternary rock matrix but also as the result of mixing processes with surface water from swamp areas and major river courses like Chari and Logone flowing from the southern Lake Chad basin regions. In such context, the interactions between groundwater and aquifer rock matrix are short (as shown by the clear under saturation of samples with respect to calcite) and thus the geochemical signature is mostly imposed by carbonates whether in situ or via the suspended particles in river water.

Along the flow lines, and according to the aging processes, isomorphic substitution with clay minerals occurs (base exchanges phenomenon) and Na^{+} and K^{+} tend to increase in a dominant way. This phenomenon is unfortunately difficult to illustrate from the dataset even if it is well documented in the literature especially for Eastern Niger (Raizi, 2008).

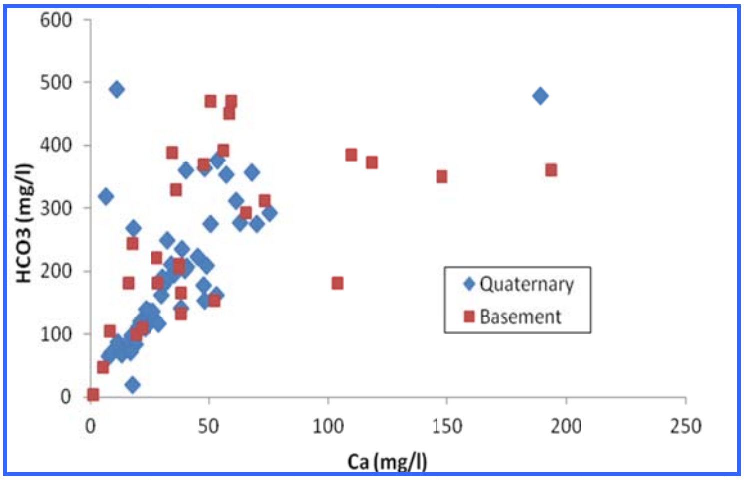


Figure 28: Ca^{2+} vs HCO_3^- in Quaternary and basement aquifer of Northern Cameroon

-Groundwater geochemistry evolution along flow lines

In addition to base exchange phenomenon entailing the decrease of Ca^{2+} and Mg^{2+} and the following increase in Na^{+} and K^{+}, sulphate are also increasing along flow lines in the direction of the Lake Chad. As shown by figure 29 this increase can be linked to the dissolution of gypsum, which is not observed commonly in the area apart for the Lake Chad vicinity and in some topographic depressions (Raizi, 2008).

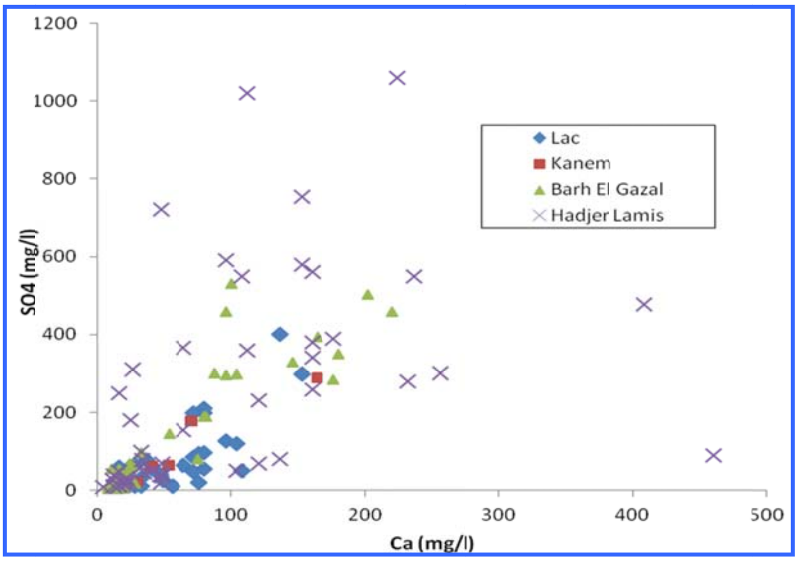


Fig. 29: Ca^{2+} vs SO_4^{2-} in Quaternary aquifer groundwater of Chad. Highest sulphate concentrations are from the Lake Chad surroundings.

-Anthropogenic fingerprint on groundwater

An important phenomenon affecting the Quaternary groundwater is the strong anthropogenic fingerprint encountered throughout the basin. Nitrate concentrations can be extremely high in some wells and boreholes over the Chad Lake basin. This is particularly true for the most densely populated zones of Northern Cameroon and Chad Lake vicinity. In Figure 30, very high concentrations can be observed in wells from the Grand Yaéré region especially for the basement crystalline groundwater samples. Quaternary groundwater is less affected by nitrate contamination in this region but concentrations above the drinking water standards are common and frequently accompanied by high concentrations in K^{+}, SO_4^{2-}, Na^{+} and Cl^{-}.

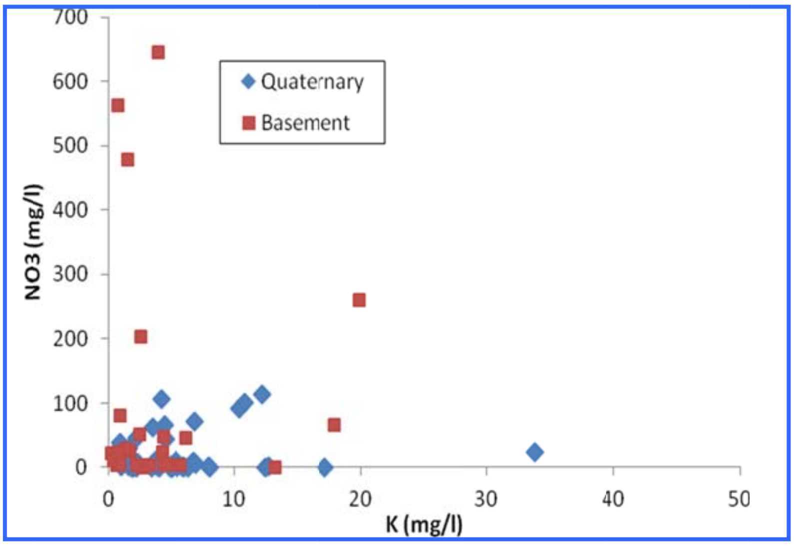


Figure 30: K^+ vs NO_3^- in groundwaters of the Quaternary and basement aquifers in Northern Cameroon.

The comparison of nitrate versus K^+ (Fig. 31) is interesting in the way that it allows identifying in terms of elements sources what is from anthropogenic origin and what is coming from evaporation/dissolution processes. For high nitrate concentrations, we generally do not observe high K^+ concentrations and for high K^+ concentration we do not have high corresponding nitrate contents. This implies two different processes to explain the origin of these elements that can be both from natural or anthropogenic origin. For samples taken from the most arid areas nitrate concentrations remain quite low apart for wells used to water animals where a high contamination of the well vicinity is registered. In the most arid areas K^+ of dissolution origin can reach very high concentrations which are perfectly correlated with the EC of groundwater. The field information provided by the counterparts are not enough relevant to allow discriminating other clearly anthropogenic origin for element like Cl^- or SO_4^{2-} which can also be of evaporation/dissolution terrigenic origin.

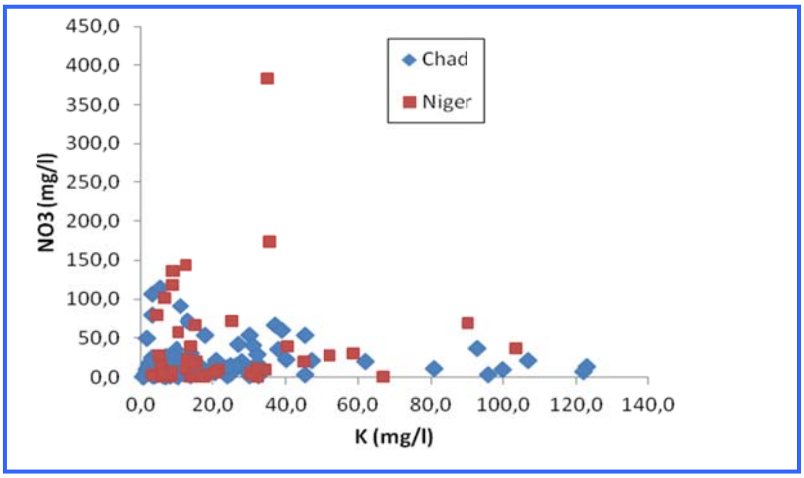


Fig. 31: K^+ *vs* NO3-the groundwaters of the Quaternary aquifer in Niger and Chad.

For the groundwater samples of CAR nitrate concentrations are quite low and all below drinking standards. Nitrate is found in wells generally used by population but since the density of inhabitants is low in this region of CAR the contamination levels are also very low.

4.4. Isotopic signature of groundwater

-Origin of groundwater

The isotopic signature of groundwater (Fig. 32) covers a very large rang of values in relation with the very large region covered but also in relation with the intense evaporation processes taking place in Central Africa. Half of the samples from Niger and Chad are positive showing strong evaporation influence. Data are globally plotted close to the Local Meteoric Water Line of Ndjamena with a shift due to evaporation influence. Groundwater from Northern Cameroon and CAR are all plotted close to the LMWL of N'Djamena and close to the GMWL. They do not show any strong evaporation influence on the samples.

The mean weighted composition of rainfall at N'Djamena for 2015 is also plotted on the graph, but is not really fitted with the groundwater signature probably due to the very short time of the rainfall isotopic survey but also due to the long distance between the Chadian capital and CAR and probably due to the difference on climate conditions with Central Chad and Eastern Niger. But if we consider more in detail the GNIP results we can find agreement between groundwater and July and August isotopic signature in rainfall, probably showing the important of these two heavy rain months on the recharge processes.

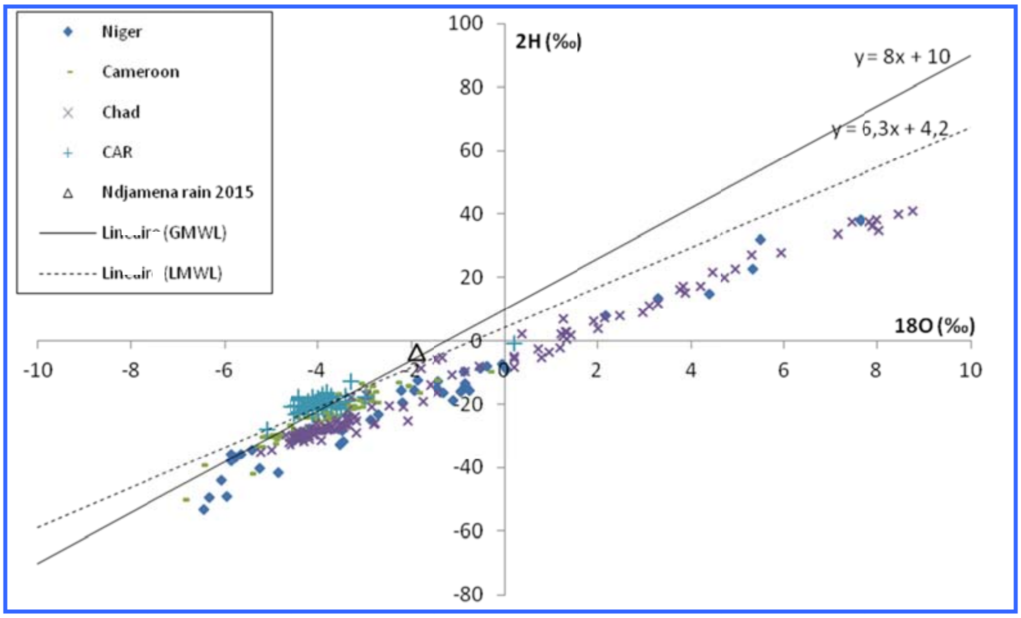


Figure 32: ^{18}O *vs* ^{2}H for Quaternary aquifer groundwater of the lake Chad Basin. LMWL is calculated from the 1964-1995 GNIP dataset.

An obvious isotopic continuum appears from these results starting from CAR at the head of the southern basin towards the humid zones of the Chari and Logone rivers in Cameroon and then to the Central Chad Basin where evaporation is the main driver of the water cycle. Very similar isotopic results were found by BGR (2010) during their investigations in Central-Southern Chad.

-Influence of evaporation processes

Evaporation processes and its variable intensity is a major feature of the isotopic signature of groundwater in the Chad Lake Basin. Very positive values can be observed which are also associated with a high EC of groundwater (Fig. 33) and thus to high mineralisation of groundwater. It is mostly the case for Chad and Niger groundwater which is isolated from contact with surface water. For shallow groundwater in contact with surface water via the rivers the evaporation signal is weak but mixing with highly mineralized water can also occur. Groundwater from CAR are not affected by evaporation and low mineralized. Northern Cameroon groundwater, closely in contact with river water show very little evaporative processes but variable mineralization, mostly related with anthropogenic influences. As previously shown, the pristine isotopic signature of groundwater seem more related to the one of the humid Central African Republic (if compared to the Bangui GNIP station for instance) and as surface and groundwater flow North in direction of the Central Chad basin their signature is evolving towards more evaporated signal and increased mineralisation.

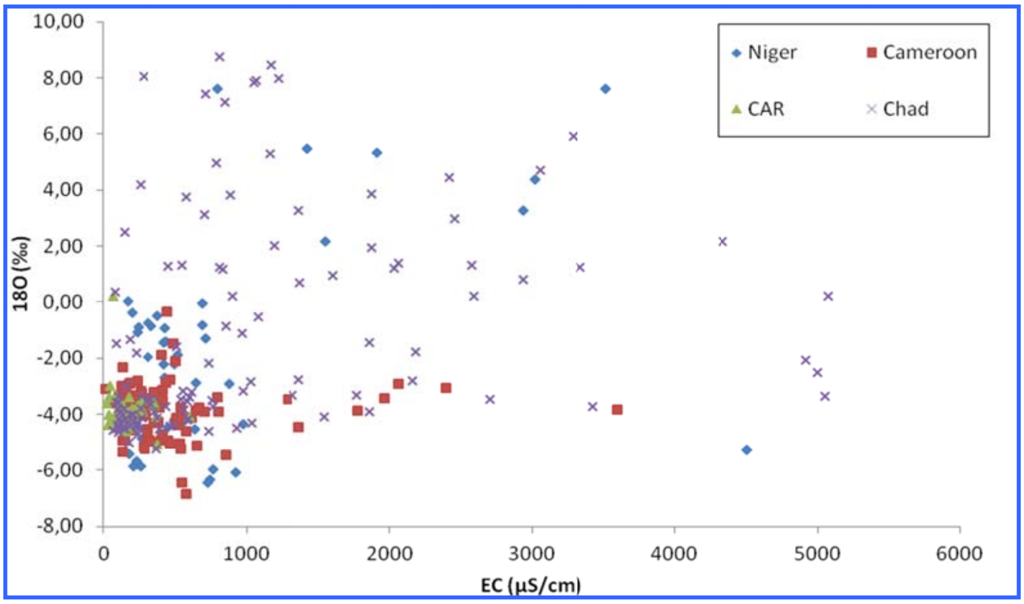


Figure 33: ^{18}O *vs* EC for groundwaters of the Quaternary aquifer in the lake Chad Basin.

-Surface water- Groundwater interaction

The major role of river water and more generally surface water has already been highlighted for the region by different authors like Ketchemen (1992) for Northern Cameroon, Djoret (2000) and Kadjangaba (2007) for N'Djamena region, Abderamane (2012) for the Chari-Baguirmi, Raizi (2008) and Genthon et al. -2015) for the Diffa region.

As clearly shown by the 2015 GNIR survey of the Chari River at N'Djamena station, the isotopic signature of surface water is strongly evolving along a single hydrological cycle and the high-water period is the episode the most prone to contribute to the shallow aquifer recharge from September to November when the stable isotope signature of river water is the most depleted (around -1‰ and -2‰ for ^{18}O and from -5‰ to 0‰ for ^{2}H). This phenomenon can also explain the dispersion of the isotopic values for the central Chadian and Eastern Nigerien groundwater samples under river water influence from the Chari and Komadougou-Yobé.

Additional recharge is also provided by the intense rainfall episodes of the rainy season over the region, and according to Figure 34 July and August seem to have a major weight in the recharge processes since their signature is mostly found in the groundwater of the region. This needs to be confirmed by continuing the measurements at N'Djamena GNIP station. This two modes recharge process has already been observed for the N'Djamena region by Kadjangaba (2007).

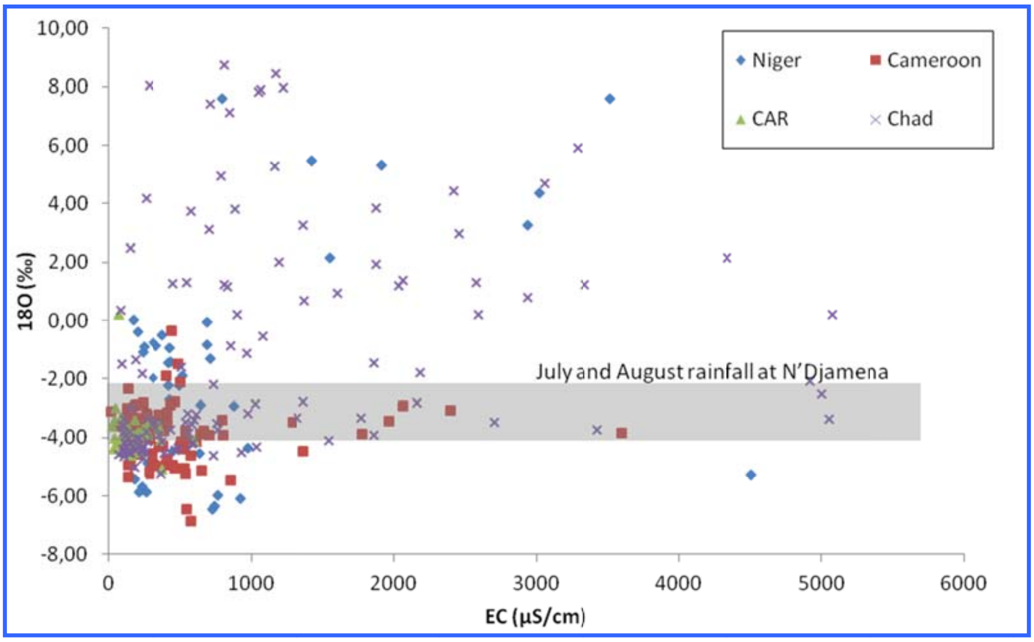


Figure 34: ^{18}O *vs* EC for groundwaters of the Quaternary aquifer in the Lake Chad Basin and isotopic signature of rainfall at N'Djamena for July and August.

-Evolution of the isotopic signature along flow lines

Even if flow lines in the Quaternary aquifer have been very imperfectly followed due to difficulties in the sampling approaches, it is possible to see some evolution at least from the Southern Lake Chad Basin towards the Central Basin. But it should be kept in mind that no hydraulic connection can be assumed for CAR and the rest of the basin. CAR groundwater is only supposed to be from CT (and most probably from lateritic levels) and crystalline basement but without being sure of it according to the very few geological investigations carried out in the region and the lack of consistency of old geological maps.

The evolution in the mineralisation evidenced previously is followed by isotopic processes modifying the groundwater signature mainly under two combined modes mixing evaporation processes and mixing with river water. In a probably more marginal way direct recharge from rainy season atmospheric water occurs but an ambiguity in the isotopic signature of river water from the high-water period and the heart of the rainy season rainwater prevent from separating both phenomenon. As a shallow unconfined aquifer, the Quaternary deposits are affected by different recharge modalities all over the extension of the aquifer covering most of the Chad Lake basin watershed.

4.5. Residence time of shallow groundwater

To evaluate residence time of groundwater within the shallow aquifer of the Quaternary, tritium measurements have been carried out in Chad, Niger and CAR. No tritium sample was analysed for Cameroon due to security restrictions in the access to the field during the project.

Considering the tritium activities up to 5 TU at maximum observed in rainwater and river water of 2015 at the GNIP and GNIR stations of N'Djamena, the tritium activities observed in the Quaternary aquifer for some wells and boreholes seem quite elevated (Fig. 35). We are here probably in the presence of remaining water from the post nuclear tests tritium pic slowly moving in a low dynamic hydrogeological environment. Values up to 16 TU are indeed surprising in this context.

Groundwater without tritium can also be observed mostly for the Chadian samples from the central Chad basin. Samples from Niger show activities in the range of modern rainfall over the region and sometimes low activities showing mixing with older water from deeper levels of the Quaternary aquifer. This is also the case for samples from central Chad with even no tritium for some wells.

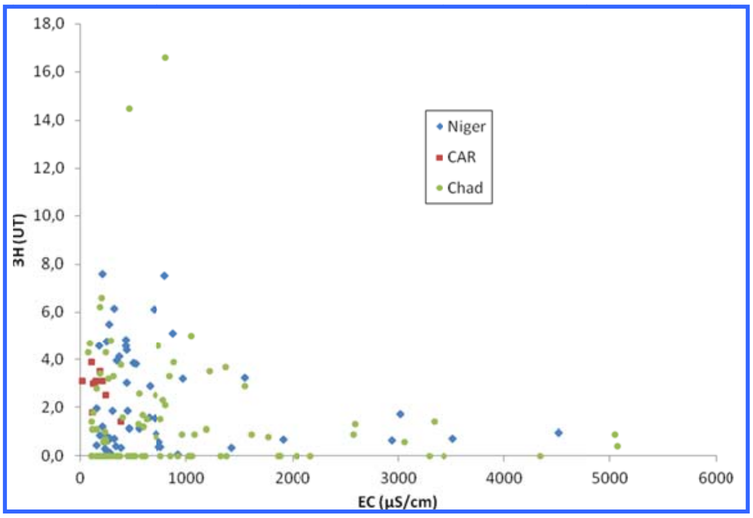


Figure 35: ^{3}H vs EC for groundwaters of the Quaternary aquifer in the Lake Chad Basin.

Water without tritium or low tritium can sometimes be quite mineralized when originating from piezometric depressions or from the vicinity of Lake Chad were evaporates are observed. Mixing of water of different origins is here evidenced. Groundwater from the Northern Cameroon all contain tritium at modern rainfall level which agrees with their situation at the boundary of the basin and their strong interactions with surface water.

Fig. 36 clearly shows the very wide dispersion of isotopic data over the territory of the Lake Chad basin. CAR groundwater samples even if not connected to the rest of the shallow hydrogeological structures can be considered as an illustration of the modern isotopic signature of groundwater in the southern head of the watershed with ^{18}O values around -4 to -3 ‰ and tritium activities between 2 and 4 TU.

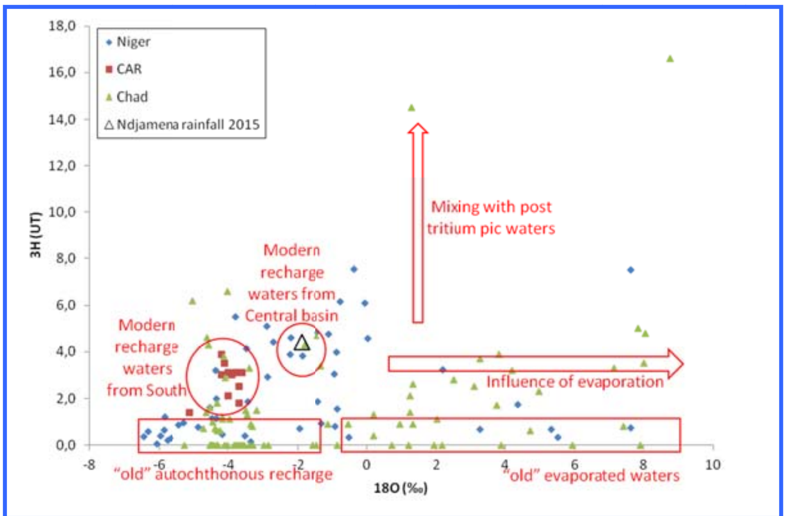


Figure 36: ^{3}H vs ^{18}O for the Quaternary aquifer groundwater of the Lake Chad Basin.

The isotopic signature of N'Djamena rainfall for 2015 is slightly more enriched in $\delta^{18}O$ and ^{3}H compared to CAR groundwater samples, which is in the logic of the climate and distance differences between the two zones. N'Djamena rainfall can be considered as representative of the local Central basin recharge by rain episodes.

Strongly evaporated water without or almost without tritium are also common in Central Chad and Eastern Niger showing that the Quaternary aquifer can host "old" groundwater dating from more than 60 years and which have previously been evaporated or mixed with evaporated water. On the contrary surprisingly high tritium content can be observed in some samples from Chad clearly showing a remnant contribution of the tritium pic in some semi-confined parts of the aquifer.

Most of the groundwater from Chad and Niger having depleted $\delta^{18}O$ are also showing low tritium activities and can be considered as slow moving autochthonous recharged water from the south-central part of the Lake Chad basin whether directly by local rainfall or by hydraulic continuity with Logone and Chari Rivers System.

5. CONCLUSIONS

This project brought new insight into the isotopic signature of surface and shallow groundwater over the lake Chad Basin with an important mass of sampling and associated data. Previous work on the basin has dealt with local approaches and on a fragmentary basis. For the first time, samples from four different neighbouring countries have been considered together. For security reasons field activities were not developed at their maximum and the different counterparts have focused their investigations on the Quaternary levels with only one sampling campaign, apart for CAR.

The IAEA-supported project RAF/7/011 highlighted major hydrogeological processes affecting the shallow aquifers of the Lake Chad basin. Amongst them the intricate relationship between surface and groundwater, especially in the southern watershed between Cameroon, CAR and Chad, where important swamp areas are lying and playing a major ecological role as both biodiversity heritage preservation and as surface water/groundwater buffering zone. The southern boundary of the Lake Chad basin appears as the water feeder of all rivers and hence part of the groundwater within the Central basin.

This project also underlined and confirmed the existence in the regional aquifers of enormous quantities of good quality groundwater able to meet the human demand for drinking and agriculture use from the Quaternary aquifer of the Lake Chad Basin. However, some limitations appeared in the groundwater access and quality especially concerning the high mineralisation level of water in some areas and at some depth which can prevent groundwater from being used. Furthermore, local contamination by nitrate and other components can be a problem in the most densely populated areas due to the lack of any protection of the wells or boreholes from animal droppings and latrines.

Deeper wells and boreholes from the Quaternary levels are constituted by relatively "old" groundwater with important residence time. However, as indicated by stable and radioactive isotopes, mixing with surface evaporated and sometimes shallow groundwater that are highly contaminated by salts and nitrates are also frequently recorded.

Within the IAEA-supported project RAF/7/011, N'Djamena GNIP station was resumed after 20 years of inactivity and a new GNIR station on the Chari at N'Djamena was settled helping to delineate the isotopic signals of surface water in the region.

The results of the project appear as very complementary to the very detailed investigations carried out by BGR from 2008 in the region of the South-eastern Chad Basin (Chad territory). The results from the IAEA-supported project RAF/7/011 fit particularly well with the BGR results and cover different zones of the watershed. Conclusions brought by both investigations are going in the same direction. The major interest of the RAF/7/011 project was to extend the investigation area of previous IAEA-supported regional and national projects, such as RAF/8/012, CAM/8/002 and CHD/8/002.

Recommendations

Based on the results achieved during the implementation of the project the IAEA-supported project RAF/7/011, it can be stated that the Lake Chad basin presents relatively good quality of groundwater consistent with the drinking water standards in most places. However, special interest should be given to:

- Improving policies and strict regulations for the protection of well catchment against wastes and animals influences to prevent local contamination (salt and nitrate) in groundwater.

- Promoting the protection of wetland areas hydraulically connected to aquifers (Chad, Niger), forested areas and soils of the watershed head (CAR, Cameroon). The swamp areas located along the Komadougou-Yobé River and the Chari-Logone Rivers must also be protected as they enhance recharge of the local aquifers.

- More field investigations for resource evaluation. Since the IAEA-supported project RAF/7/011 was not able to provide any insight into the deeper aquifers of the region which are under-documented and under-investigated. A potential objective for further research would be to focus investigations on the deeper wells and boreholes tapping the aquifer levels of the Pliocene and Continental Terminal. The strong potential of these aquifer levels needs to be appreciated as well as their transboundary aspects implications. In addition to the stable isotope investigations on the groundwater, residence time particularly need to be determined as groundwater flow velocities are probably very slow in these confined aquifers.

- More investigations for groundwater renewal dynamics evaluation particularly for the assessment for the potential interactions between the Quaternary aquifer with main river courses and Lake Chad which is absolutely strategic for the recharge processes. This concept of surface/groundwater interrelationship should be integrated in the Strategic Management Program of the basin.

- Adding new GNIP and GNIR stations allowing collecting more information from both atmospheric and surface water in order go deeper into hydrological processes at the scale of the different tributaries (Ouham, Chari, Logone, Komadougou-Yobé).

6. REFERENCES

BEYERLE U., RUEEDI J., LEUENBERGER M., AESCHBACH-HERTIG W., PEETERS F., KIPFER R. (2003): Evidence for periods of wetter and cooler climate in the Sahel between 6 and 40 kyr BP derived from groundwater. Geophysical Research Letters, VOL. 30, N°. 4-1173.

BGR (2009): A review of the groundwater situation in the Lake Chad Basin. Report, 18p.

BGR (2012): Groundwater needs assessment in the Lake Chad Basin. Report, 14p.

BGR (2013a): Discharge Measurements at Chari, Logone and Koulambou River, Chad (July 2013). Report , 18p.

BGR (2013b): 2nd Mission on Discharge Measurements at Chari, Logone and Koulambou River, Chad (December 2013). Report, 21p.

BGR (2014a): Groundwater quality investigations in the Kanem and Bahr el Ghazal regions, Chad. Report, 41p.

BGR (2014b): Groundwater quality investigations in the Lower Logone floodplain in April-May 2013

BGR (2016): Groundwater-Surface Water interaction in the Lower Logone floodplain. Report, 49p.

BORONINA A., RAMILLIEN G. (2008): Application of AVHRR imagery and GRACE measurements for calculation of actual evapotranspiration over the Quaternary aquifer (Lake Chad Basin) and validation of groundwater models. Journal of Hydrology, 348, 98-109.

BOUCHEZ C. (2015): Bilan et dynamique des interactions rivières-lac(s)-aquifères dans le basin hydrologique du lac Tchad. Approche couplée géochimie et modélisation des transferts. Thèse Doct. Univ. Aix-Marseille.

BOUCHEZ C., DESCHAMPS P., GONCALVES J., HAMELIN B., SYLVESTRE F., DOUMNANG J.C., MAHAMAT NOUR A., BABA GONI I., FAVREAU G., GENTHON P., SEIDEL J.L. (2015): Investigation of 36Cl distribution: towards a new estimation of groundwater residence times in the confined aquifer of the LCB? Procedia Earth and Planetary Science, 13, 147-150.

BOUCHEZ C., GONCALVES J., DESCHAMPS P., VALLET-COULOMB C., HAMELIN B., DOUMNANG J.C., SYLVESTRE F. (2016): Hydrological, chemical, and isotopic budgets of Lake Chad: a quantitative assessment of evaporation, transpiration and infiltration fluxes. Hydrol. Earth Syst. Sci., 20, 1599-1619.

BOULVERT Y. (1987): Importance réduite du Continental Terminal en Centrafrique. Doc ORSTOM.

BRG (2010): Investigation on water quality in the southeastern part of the Lake Chad Basin. Report, 35p.

CARMOUZE J.P. (1976): Les grands traits de l'hydrologie et de l'hydrochimie du Lac Tchad. Cahier O.R.S.T.O.M., sér. Hydrobiologie, vol. X, N° 1, 1976, pp. 33-56

CANDELA L., ELORZA F.J., TAMOH K., JIMENEZ-MARTINEZ J., AURELI A. (2014): Groundwater modelling with limited data sets : the Chari-Logone area (Lake Chad Basin, Chad). Hydrological Processes, 28, 3714-3727.

DJORET D. (2000): Etude de la recharge de la nappe du Chari Baguirmi (Tchad) par les méthodes chimiques et isotopiques. Thèse Doct. Univ. Avignon.

DJEBEBE-NDJIGUIM C.L., HUNEAU F., DENIS A., FOTO E., MOLOTO-A-KENGUEMBA G., CELLE-JEANTON H., GAREL E., JAUNAT J., MABINGUI J., LE COUSTUMER P. (2013): Characterization of the aquifers of the Bangui urban area as an alternative drinking water supply resource. Hydrological Sciences Journal, 58, 1760-1778.

EBERSCHWEILER C. (1993): Monitoring and management of groundwater resources in the Lake Chad Basin: mapping of aquifers water resource management-final report. R 35 985, CBLT-BRGM, Orléans, France.

FANTONG W.Y., SATAKE H., AYONGHE S.N., AKA F.T., ASAI K. (2009): Hydrochemical controls and usability of groundwater in the semi-arid Mayo Tsanaga River Basin: far north province, Cameroon. Environ. Geol., 58, 1281-1293.

FAURE H., FONTES J.C., GISCHLER C.E., MOOK W.G., VOGEL J.C. (1970): Un exemple d'étude d'hydrogéologie isotopique en pays semi-aride, le bassin du lac Tchad. Journal of Hydrology, 10, 141-150.

FONTES, J.C., MAGLIONE G., ROCHE M.A. (1969): Eléments d'hydrologie isotopique dans le bassin du lac Tchad. IAEA Proceedings, Vienna, 209-219.

FONTES J.C., GONFIANTINI R., ROCHE M.A. (1970): Deutérium et oxygène-18 dans les eaux du lac Tchad. IAEA Proceedings, Vienna, IAEA-SM-129/23, 377-404.

GASSE F. (2000): Hydrological changes in the African tropics since the Last Glacial Maximum. Quat. Sci. Rev., 19, 189-211.

GENTHON P., HECTOR B., LUXEREAU A., DESCLOITRE M., ABDOU H., HINDERER J., BAKALOWICZ M. (2015): Groundwater recharge by Sahelian rivers-consequences for agriculture development: example from the lower Komadugu Yobe River (Eastern Niger, Lake Chad Basin). Environ. Earth Sci., 74, 1291-1302.

GONI I.B. (2006): Tracing stable isotope values from meteoric water to groundwater in the southwestern part of Chad basin. Hydrogeology Journal, 14, 742-752.

HUNEAU F., DAKOURE D., CELLE-JEANTON H., VITVAR T., ITO M., COMPAORE N.F., TRAORE S., JIRAKOVA H., LE COUSTUMER P. (2011): Flow pattern and residence time of groundwater within the south-eastern Taoudeni sedimentary basin (Burkina Faso, Mali). Journal of Hydrology, 409, 423-439.

JOSEPH A., FRANGI J.P., ARANYOSSY J.F. (1992): Isotope characteristic of meteoric water and groundwater in the Sahelo-Sudanese zone. J. of Geophysical Research, 97, 7543-7551.

KADJANGABA E. (2007) : Etude hydrochimique et isotopique du système zone non saturée-nappe dans la zone urbaine de N'Djamena : impact de la pollution. Thèse Doct. Univ. Avignon.

KETCHEMEN B. (1992): Etude hydrogéologique du Grand Yaéré (extrême nord du Cameroun), synthèse hydrogéologique et étude de la recharge par les isotopes de l'environnement. Thèse 3ième cycle, Univ. Cheikh Anta Diop, Dakar.

LEDUC C., SABLJAK S., TAUPIN J.D., MARLIN C., FAVREAU G. (2000): Recharge of Quaternary water table in the northwestern Lake Chad basin (southeastern Niger) estimated from isotopes. C.R. Acad. Sci. Paris, Earth and Planetary Sceinces, 330, 355-361.

MADUABUCHI C., FAYE S., MALOSZEWSKI P. (2006): Isotope evidence of paleorecharge and palaeoclimate in the deep confined aquifers of the Chad Basin, NE Nigeria. Science of the Total Environment, 370, 467-479.

MASSUEL S. (2001). Modélisation hydrodynamique de la nappe phréatique quaternaire du bassin du lac Tchad. Mémoire DEA Sciences de l'Eau, Univ. Montepllier-2.

NGOUNOU NGATCHA B., MUDRY J., ARANYOSSY J.F., NAAH E., SARROT REYNAULT J. (2007): Apport de la géologie, de l'hydrogéologie et des isotopes de l'environnement à la connaissance des "nappes en creux" du Grand Yaéré (Nord Cameroun). Revue des Sciences de l'Eau, 20, 29-43.

OLIVRY J.C., CHOURET A., VUILLAUME G., LEMOALLE J., BRICQUET J.P. (1996): Hydrologie du Lac Tchad. Editions ORSTOM, Paris, 266p.

RAIZI R. (2008): Etude géochimique et hydrodynamique de la nappe libre du Bassin du Lac Tchad dans les regions de Diffa (Niger oriental) et du Bornou (nord-est du Nigeria). These Doct. Univ. Montpellier, France, 212p.

RAJKUMAR Y., XU Y. (2011): Protection of borehole water quality in Sub-Saharan Africa using minimum safe distances and zonal protection. Water Resour. Manage., 25, 3413-3425.

ROCHE (1980): Traçage naturel salin et isotopique des eaux du système hydrologique de lac Tchad. Travaux et documents de l'ORSTOM, Paris, 383p.

SCHNEIDER J.L., WOLFF J.P. (1992) : Carte géologique et carte hydrogéologique au 1/1500000 de la République du Tchad, Mémoire Explicatif. Document BRGM n°209, vol. 1 & 2, 689p.

SWEZEY C. (2001): Eolian sediment responses to late Quaternary climate changes: temporal and spatial patterns in the Sahara. Palaeogeography, Palaeoclimatology, Palaeoecology, 167, 119-155.

TRAVI Y., MUDRY J. (1997): Méthode pour l'évaluation et la gestion du risque nitrate dans les aquifères de socle de la zone sahélienne d'Afrique de l'Ouest. Hydrogéologie, 1, 13-21.

WALLIN B., GAYE C., GOURCY L., AGGARWAL P. (2005): Isotope methods for management of shared aquifers in Northern Africa. Ground Water, 43, 744-749.

WIRMVEM M.J., OHBA T., FANTONG W.Y., AYONGHE S.N., SUILA J.Y., ASAAH A.N.E., ASAI K., TANYILEKE G., HELL J.V. (2014): Monthly $\delta^{18}O$, δD and Cl^- characteristics of precipitation in the Ndop plain, Northwest Cameroon: Baseline data. Quaternary International, 338, 35-41.

ACRONYMS

B.P.: Before Present

CAM: Cameroon

CAR: Central African Republic

CT: Continental Terminal

EC: Electric Conductivity

GMWL: Global Meteoric Water Line

GNIP: Global Network of Isotopes in Precipitation

GNIR: Global Network of Isotopes in Rivers

LMWL: Local Meteoric Water Line

T: Temperature

TDS: Total Dissolved Salts

TP: Travaux Publics

TU: Tritium Unit

ANNEXES

Annex 1

Chad data generated in the framework of the IAEA-supported project RAF/7/011 - geochemical data

Chad data generated in the framework of the IAEA-supported RAF/7/011 - isotope data

Annex 2

Niger data generated in the framework of the IAEA-supported project RAF/7/011

Annex 3

Cameroon data generated in the framework of the IAEA-supported project RAF/7/011

Annex 4

Central African Republic data generated in the framework of the IAEA-supported project RAF/7/011

Annex 1: Chad data generated in the framework of the IAEA-supported project the IAEA-supported project RAF/7/011 - geochemical data

	N°	Sample ID	Site	Longitude	Latitude	T (˚C)	pH	EC (µS/cm)	Ca2+	Mg2+	Na+	K+	HCO3-	CL-	SO42-	NO3-
1	1	Ergueye	Barh El Gazal	16°38'35''	13°41'59"	30,8	7,4	486,0	24,0	2,4	55,4	7,2	109,8	29,0	58,0	6,0
2	2	Goz billah	Barh El Gazal	16°32'11''	14°04'38''	31,4	9,4	3284,0	96,0	4,9	407,0	37,0	463,6	190,0	459,0	66,9
3	19	Moura 3	Barh El Gazal	16°32'09"	13°39'44"	31,5	7,9	446,0	16,0	1,0	42,7	3,2	9,8	15,0	46,0	79,0
4	20	Ergueye I	Barh El Gazal	16°38'25"	13°41'49"	32,2	8,0	613,0	10,4	1,5	74,1	5,2	29,3	17,0	56,0	114,0
5	21	Moura 2	Barh El Gazal	16°31'24"	13°39'57"	31,1	7,3	425,0	27,2	11,7	34,8	3,1	14,6	19,0	67,0	107,0
6	26	Moussoro Anas Ibn	Barh El Gazal	16°28'54"	13°38'45"	30,5	7,5	298,0	20,8	2,9	31,7	4,6	73,2	20,0	34,0	7,8
7	30	Moussoro Marché	Barh El Gazal	16°29'28"	13°38'41"	28,6	7,8	264,0	20,0	2,4	22,9	3,0	63,4	14,0	33,0	2,0
8	31	Moura	Barh El Gazal	16°32'14"	13°40'41"	30,4	7,8	341,0	17,6	2,9	41,3	2,6	102,5	29,0	9,0	5,0
9	38	Tororo II	Barh El Gazal	16°45'16"	13°22'45"	30,2	7,2	189,0	17,6	3,9	22,7	2,2	78,1	12,0	8,0	17,0
10	39	Kawachou	Barh El Gazal	16°52'32"	13°20'58"	33,5	8,0	105,0	8,0	1,0	20,0	4,2	46,4	13,0	5,0	8,0
11	40	Grantessi	Barh El Gazal	16°41'40"	13°56'06"	32,9	6,8	1379,0	88,0	87,5	402,0	8,6	805,2	240,0	302,0	29,0
12	42	Kérimatori	Barh El Gazal	15°57'18"	13°09'56"	30,0	6,8	3125,0	176,0	14,6	505,0	27,0	927,2	300,0	285,0	42,0
13	43	Delep Droussou	Barh El Gazal	16°19'05"	13°19'40"	30,0	6,8	183,0	13,6	1,5	16,9	4,1	48,8	10,0	20,0	9,0
14	44	Bindiri	Barh El Gazal	16°00'15"	13°12'55"	28,9	7,8	222,0	16,0	1,2	22,0	9,7	58,6	14,0	5,0	35,0
15	48	Riglass	Barh El Gazal	16°00'17"	13°15'01"	30,0	7,4	204,0	13,6	1,5	28,0	3,3	53,7	16,0	35,0	1,7
16	49	Trawarou	Barh El Gazal	16°11'46"	13°17'00"	30,7	7,5	111,0	8,0	1,0	7,6	3,8	24,4	10,0	7,0	1,2
17	50	Gara I	Barh El Gazal	15°58'15"	13°11'20"	29,9	6,9	569,0	24,0	4,9	65,0	7,4	158,6	40,0	54,0	6,2
18	52	Tchoukou	Barh El Gazal	16°15'32"	13°33'32"	31,3	6,5	219,0	13,6	1,9	23,4	7,5	73,2	15,0	5,0	17,0
19	53	Wadi Wowi	Barh El Gazal	16°03'49"	13°28'41"	30,1	6,1	198,0	13,6	1,5	20,0	5,3	65,9	13,0	4,0	9,0
20	55	Tororo Kaleri	Barh El Gazal	15°58'08"	13°21'56"	29,0	6,9	337,0	20,8	1,9	26,0	12,0	85,4	22,0	14,0	9,0
21	60	Koumagaye Obi	Barh El Gazal	16°02'00"	13°30'23"	29,1	6,4	1876,0	104,0	29,2	271,0	31,0	512,4	110,0	299,0	41,0
22	62	Katé Katé	Barh El Gazal	16°00'44"	13°23'10"	28,4	5,2	468,0	24,0	9,7	46,0	8,5	119,6	40,0	38,0	18,0
23	64	Gontour	Barh El Gazal	16°15'57"	13°16'34"	29,9	7,3	140,0	8,0	1,2	12,0	4,7	31,7	10,0	10,0	6,0
24	65	Mouzragui	Barh El Gazal	15°59'03"	13°19'48"	29,8	7,2	426,0	16,0	9,7	45,0	9,1	97,6	26,0	55,0	14,0
25	68	Liguédjemé	Barh El Gazal	15°57'05"	13°15'06"	29,2	7,4	849,0	24,0	14,6	72,0	14,0	170,8	40,0	68,0	30,2
26	69	Mouzarag	Barh El Gazal	15°58'07"	13°17'17"	29,5	7,4	311,0	17,6	8,7	28,0	18,0	75,6	20,0	28,0	53,0
27	72	Hanga	Barh El Gazal	15°39'59"	13°54'16"	32,3	7,4	230,0	15,2	1,2	20,0	6,6	73,2	13,0	9,0	0,0

	N°	Sample ID	Site	Longitude	Latitude	T (˚C)	pH	EC (µS/cm)	Ca2+	Mg2+	Na+	K+	HCO3-	CL-	SO42-	NO3-
28	76	Djasllali Toutoumanga	Barh El Gazal	15°42'30"	13°48'25"	30,8	7,3	638,0	32,0	9,7	87,0	14,0	146,4	60,0	96,0	23,0
29	79	Safa Djoula	Barh El Gazal	15°49'54"	13°38'27"	31,0	6,6	2177,0	180,0	7,3	406,0	40,0	780,8	190,0	350,0	22,0
30	82	Diguine 1	Barh El Gazal	15°45'32"	13°48'24"	31,9	7,1	3432,0	202,4	1,2	628,0	93,0	1049,2	310,0	504,0	37,0
31	0	Michemiré	Barh El Gazal	15°44'42"	13°49'20"	30,8	7,3	1403,0	164,0	21,9	516,0	21,0	902,8	240,0	394,0	21,0
32	84	Diguine 2	Barh El Gazal	15°44'38"	13°48'04"	31,3	7,3	3400,0	145,6	16,0	654,0	81,0	1073,6	544,0	330,0	11,0
33	85	NGali Taher	Barh El Gazal	15°48'54"	13°54'52"	32,8	7,6	354,0	28,0	7,3	39,8	6,6	122,0	30,0	19,0	25,5
34	88	Boukoua 1	Barh El Gazal	15°43'30"	13°50'54"	31,9	7,4	252,0	19,2	3,4	24,0	8,6	73,2	24,0	7,0	19,2
35	90	Birtoum	Barh El Gazal	15°54'27"	13°52'40"	29,6	7,1	2868,0	220,0	41,3	455,0	45,0	878,4	290,0	460,0	53,7
36	91	Bem Bem	Barh El Gazal	15°54'44"	13°51'30"	30,8	7,1	2822,0	100,0	82,6	446,0	28,0	707,6	250,0	530,0	19,3
37	92	Tritroné	Barh El Gazal	15°50'34"	13°52'56"	30,7	7,9	1056,0	75,2	1,2	201,0	14,0	439,2	170,0	80,0	13,3
38	95	Younga	Barh El Gazal	15°57'30"	13°50'06"	31,0	7,2	1156,0	81,6	33,0	178,0	20,0	414,8	120,0	190,0	13,2
39	96	Salal	Barh El Gazal	17°13'11"	14°50'51"	30,5	9,5	8250,0	1080,0	63,2	924,0	107,0	3586,8	550,0	957,0	21,0
40	97	Saf	Barh El Gazal	17°04'49"	14°37'24"	30,9	7,3	4074,0	96,0	34,0	397,0	32,0	683,2	260,0	297,0	29,0
41	99	Mandjoura Cl	Barh El Gazal	17°04'43"	13°49'13"	33,2	7,6	920,0	80,0	38,9	211,0	19,0	463,6	140,0	190,0	8,0
42	100	Andrabate	Barh El Gazal	16°41'40"	13°56'30"	32,1	7,1	512,0	53,6	12,6	64,5	11,5	122,0	60,0	145,0	5,0
43	1	MOYTO	Hadjer Lamis	163336	123456	28,8	7,0	561,0	20,8	2,4	16,6	24,0	75,6	25,0	22,0	11,0
44	6	AMSAKINE	Hadjer Lamis	163359	125252	30,4	7,5	2713,0	96,0	24,3	283,0	5,0	185,4	190,0	590,0	10,0
45	7	ARADAH	Hadjer Lamis	164211	125650	29,5	7,52	590,0	32,8	8,3	34,8	1,4	75,6	38,0	79,0	5,0
46	9	DARASSALAM	Hadjer Lamis	162112	124844	28,8	7,1	4920,0	112,0	43,7	581,0	11,0	488,0	250,0	1020,0	13,0
47	10	BISNEY	Hadjer Lamis	161014	124049	29,0	7,2	5000,0	176,0	9,7	300,0	5,0	592,9	170,0	390,0	21,0
48	11	GAMBIR	Hadjer Lamis	164501	123158	30,5	7,66	878	48,0	9,7	151,8	4,2	409,9	24,0	69,0	12,0
49	15	AB IREBI	Hadjer Lamis	164541	121756	30,2	7,4	463,0	21,6	2,4	25,0	1,2	87,8	12,0	15,0	5,0
50	16	GRELKA	Hadjer Lamis	164933	121130	31,4	7,4	379,0	18,4	1,2	22,5	0,7	83,0	9,0	17,0	1,0
51	17	AMFINEDIK	Hadjer Lamis	164910	120630	30,7	7,3	217,0	16,0	1,0	13,2	0,8	43,7	11,0	11,0	0,0
52	19	AMBRORAYE	Hadjer Lamis	162821	120621	31,7	7,2	579,0	11,2	6,8	31,0	1,6	73,2	16,0	28,0	9,0
53	20	Andreb	Hadjer Lamis	162736	120951	29,9	7,2	576,0	16,0	14,6	72,0	2,3	170,8	30,0	47,0	14,0
54	23	AMGIOTTO	Hadjer Lamis	162152	121231	30,9	7,3	1060,0	12,0	12,2	55,0	1,9	170,8	20,0	38,0	7,0
55	41	Djarmaya	Hadjer Lamis	150400	122344	31,1	6,8	768,0	48,0	11,2	89,0	8,0	239,1	60,0	36,0	22,0

	N°	Sample ID	Site	Longitude	Latitude	T (˚C)	pH	EC (µS/cm)	Ca2+	Mg2+	Na+	K+	HCO3-	CL-	SO42-	NO3-
56	42	Djimeze Al Himdé	Hadjer Lamis			32,1	6,9	2650,0	256,0	77,8	320,0	10,0	780,8	410,0	300,0	0,0
57	44	Amsinet	Hadjer Lamis			30,8	6,7	2170,0	236,0	1,2	223,0	11,0	610,0	33,0	550,0	22,2
58	49	Kinebor Fadjé	Hadjer Lamis			31,2	6,8	697,0	46,6	2,3	65,0	6,8	167,1	40,0	39,0	27,0
59	50	Naala	Hadjer Lamis			32,0	6,6	4100,0	408,0	43,7	618,0	3,1	1512,8	390,0	478,0	25,0
60	51	Am Soukar 1	Hadjer Lamis			31,0	6,9	529,0	40,0	14,6	39,4	7,0	146,4	40,0	51,0	3,2
61	52	Am soukar 2	Hadjer Lamis			30,2	7,0	838,0	24,8	33,5	101,0	10,0	219,6	40,0	180,0	3,2
62	53	Djoumarassi	Hadjer Lamis			29,8	7,1	677,0	34,4	9,2	68,0	1,5	151,3	33,0	45,0	49,3
63	55	Kilmé	Hadjer Lamis			29,3	6,6	437,0	23,2	11,7	39,0	3,8	131,8	25,0	23,0	17,0
64	57	Amdedoua	Hadjer Lamis			30,4	6,3	798,0	32,0	9,7	54,0	6,0	85,4	48,0	100,0	1,6
65	58	Karmé	Hadjer Lamis			30,7	6,7	7221,0	224,0	38,9	532,0	11,0	244,0	470,0	1060,0	90,5
66	59	Andjane	Hadjer Lamis			29,8	6,8	1870,0	160,0	9,7	145,0	9,0	292,8	140,0	380,0	4,5
67	63	Guitté	Hadjer Lamis			28,9	7,1	1253,0	64,0	29,2	158,0	8,0	414,8	60,0	155,0	6,0
68	65	Mani Cl	Hadjer Lamis			30,1	7,2	306,0	21,6	12,6	38,0	4,2	146,4	19,0	33,0	3,7
69	67	Irack	Hadjer Lamis			29,4	7,0	962,0	48,0	9,7	109,0	8,0	268,4	70,0	38,0	14,0
70	68	Rigueyek	Hadjer Lamis			31,2	6,8	552,0	47,2	0,5	50,0	7,6	170,8	40,0	21,0	9,4
71	70	Tourba Ecole	Hadjer Lamis			30,9	6,7	2465,0	160,0	34,0	213,0	9,0	378,2	140,0	560,0	3,0
72	71	Amdogo	Hadjer Lamis			29,8	6,7	2064,0	152,0	53,5	201,0	7,0	439,2	120,0	580,0	6,0
73	73	Hillé Adjid	Hadjer Lamis			30,5	7,0	1320,0	120,0	9,7	121,0	6,0	463,6	80,0	70,0	2,4
74	74	Sidjé	Hadjer Lamis			31,1	7,3	1778,0	136,0	9,7	143,0	8,0	500,2	100,0	80,0	1,9
75	75	Hadjer Lamis	Hadjer Lamis			30,8	8,3	2083,0	160,0	4,9	298,0	9,0	658,8	120,0	260,0	3,8
76	78	Tharé	Hadjer Lamis			29,8	8,0	1544,0	104,0	9,7	130,0	2,0	463,6	80,0	50,0	12,0
77	79	Bachom	Hadjer Lamis	153918	125045	32,1	6,8	2936,0	232,0	29,2	310,0	9,0	1024,8	150,0	280,0	26,0
78	80	Amra	Hadjer Lamis			31,9	7,1	1160,0	32,0	7,8	122,0	8,0	292,8	50,0	60,0	9,5
79	81	Kara Maloumoudary	Hadjer Lamis			30,8	7,1	170,0	4,0	0,5	25,0	3,0	26,8	11,0	9,0	23,0
80	82	Kieri Kouka	Hadjer Lamis	153353	130548	31,3	7,4	142,0	16,0	4,9	18,0	2,0	78,1	7,0	14,0	6,0
81	83	Karassa	Hadjer Lamis	154220	130214	30,4	6,9	2347,0	112,0	14,6	319,0	8,0	683,2	6,0	360,0	14,0
82	86	Mouloumary	Hadjer Lamis	153914	125057	30,5	7,0	2425,0	160,0	24,3	234,0	8,0	710,0	110,0	340,0	6,0
83	87	Massakory	Hadjer Lamis	154259	125828	31,4	6,9	1165,0	460,0	120,0	6,0	38,9	56,0	475,8	90,0	60,0

	N°	Sample ID	Site	Longitude	Latitude	T (˚C)	pH	EC (µS/cm)	Ca2+	Mg2+	Na+	K+	HCO3-	CL-	SO42-	NO3-
84	89	Kieki I	Hadjer Lamis	153314	125413				26,4	18,0	457,0	27,0	683,2	150,0	310,0	15,0
85	90	Achip Kermai	Hadjer Lamis	155051	130502				108,0	34,0	545,0	13,0	707,6	202,0	550,0	72,0
86	91	Marabari	Hadjer Lamis						12,0	1,2	12,3	3,0	36,6	10,0	11,0	6,4
87	92	Amdjamena	Hadjer Lamis	153222	124609				16,0	38,9	298,0	24,0	585,6	130,0	250,0	2,0
88	93	Abkarno	Hadjer Lamis	154953	130129				47,2	78,2	665,0	25,0	829,6	260,0	720,0	4,1
89	94	Djouroup	Hadjer Lamis	153436	130138				64,0	4,9	568,0	26,3	732,0	230,0	365,0	15,0
90	95	Hachim Angalti	Hadjer Lamis	155013	130755				120,0	24,3	435,0	24,0	805,2	250,0	232,0	12,0
91	98	Afono	Hadjer Lamis	154128	125722				152,0	53,5	689,0	38,0	1024,8	290,0	754,0	36,0
92	11	Tchio I K.	Kanem	151822	140512	31,7	6,8	420,0	24,0	3,9	28,0	5,0	92,7	22,0	25,0	5,2
93	20	Moto Mao	Kanem	151812	140732	31,1	7,0	437,0	29,6	3,9	24,0	3,0	78,1	26,0	22,0	14,0
94	56	Sassanga	Kanem	154255	141850	32,9	7,4	1105,0	40,0	9,7	53,0	6,0	170,8	30,0	62,0	2,0
95	73	Djokou Samaraye	Kanem			30,0	6,7	1028,0	70,4	14,1	98,0	3,7	292,8	46,0	178,0	5,4
96	75	Mourdjigui	Kanem			30,0	7,3	837,0	52,8	14,6	60,0	2,3	244,0	21,0	65,0	7,0
97	77	Tchoroganti	Kanem	154907	134437	32,8	7,2	4222,0	164,0	9,7	301,0	8,0	854,0	6,0	290,0	3,4
98	74	Mathiou I	Lac	141007	140420	30,7	7,7	5070,0	96,0	63,2	967,0	123,0	2220,4	390,0	127,0	14,0
99	2	Boultou	Lac	151510	133455	31,2	7,8	738,0	24,0	4,9	80,0	13,9	187,9	22,0	59,0	2,0
100	6	koulouhoubazo	Lac	150021	133713	31,2	7,4	316,0	24,0	1,0	25,0	11,7	85,4	20,0	25,0	11,2
101	7	Kounda	Lac	150021	133713	31,4	7,5	343,0	25,6	0,5	27,0	17,3	90,3	23,0	20,0	9,0
102	73	Gabdji	Lac	140646	140805	30,9	7,9	4340,0	108,0	17,0	753,0	96,0	1878,8	350,0	51,0	3,4
103	10	Ndjaoromki	Lac	152338	133213	31,1	8,2	618,0	32,0	4,9	75,0	7,4	195,2	35,0	31,0	10,0
104	72	Kiskawa	Lac	135504	141425	31,1	8,0	3340,0	76,0	2,4	453,0	122,0	1256,6	150,0	20,0	7,0
105	12	kourna 1	Lac	151826	133157	31,3	7,4	1319,0	80,0	9,7	130,0	45,0	292,8	70,0	200,0	3,4
106	13	Kani-Katia	Lac	151600	133058	31,6	7,6	602,0	36,0	2,4	55,0	9,1	134,2	13,0	78,0	6,7
107	14	karoua	Lac	151443	133213	31,8	7,6	242,0	14,4	1,9	15,0	14,5	48,8	20,0	27,0	7,7
108	15	Bara Badeleri	Lac	152027	133346	31,7	7,7	410,0	16,0	4,9	29,0	30,0	92,7	6,0	60,0	2,3
109	16	Ouné 1	Lac	152348	133506	31,6	7,7	2580,0	80,0	29,2	328,0	100,0	829,6	230,0	54,0	9,0
110	17	kirdjorom	Lac	152844	133502	32,4	7,9	1206,0	64,0	9,7	205,0	32,4	512,4	110,0	65,0	2,4
111	18	Iski	Lac	153036	133511	32,4	8,4	478,0	16,0	3,4	53,0	17,6	112,2	21,0	53,0	8,2

	N°	Sample ID	Site	Longitude	Latitude	T (˚C)	pH	EC (µS/cm)	Ca2+	Mg2+	Na+	K+	HCO3-	CL-	SO42-	NO3-
112	19	koulkouruom	Lac	152345	133622	30,3	8,0	1167,0	46,4	5,8	104,0	62,2	341,6	60,0	42,0	20,0
113	39	Saoua B	Lac	144510	132627	31,8	7,3	2030,0	76,0	2,4	338,0	18,5	707,6	150,0	92,0	4,0
114	56	Malmairie	Lac	140826	133900	31,9	7,9	1874,0	76,0	2,4	220,0	30,0	536,8	80,0	95,0	53,4
115	26	Bini Ouara	Lac	152915	133752	31,5	7,9	3060,0	80,0	9,7	527,0	47,0	839,4	290,0	210,0	21,0
116	43	Toutou	Lac	144916	133154	32,0	7,3	1769,0	104,0	9,7	120,0	25,0	463,6	40,0	121,0	15,0
117	53	Polder Tala	Lac	144003	133353	30,8	7,5	1558,0	152,0	4,4	224,0	20,5	478,2	94,0	298,0	6,0
118	11	kioua	Lac	151443	133213	30,0	7,8	1190,0	56,0	4,9	97,0	7,0	292,8	60,0	10,0	14,0
119	40	Maar Saker	Lac	143113	133046	32,8	7,4	1082,0	72,0	4,9	108,4	7,8	244,0	23,0	200,0	1,2
120	60	Bagassola	Lac	141900	133200	28,4	7,2	884,0	72,0	4,9	80,0	13,8	317,2	6,0	85,0	19,0
121	51	Boulerom	Lac	145413	133017	31,5	7,3	730,0	56,0	4,9	52,0	15,1	292,8	6,0	12,0	6,0
122	45	Douboulboul N.	Lac	144628	133230	32,5	7,5	436,0	20,0	1,9	18,0	5,7	73,2	10,0	21,0	7,0
123	46	Dolé I	Lac	144612	133243	32,0	7,4	1001,0	80,0	4,9	51,0	10,6	126,9	82,0	96,0	10,5
124	48	Karaka	Lac	144741	132853	31,4	7,5	2630,0	136,0	14,6	526,0	15,5	805,2	310,0	400,0	13,0
125	50	Meromkoura	Lac	144934	132832	32,1	8,0	371,0	40,0	1,0	31,0	5,4	122,0	9,0	56,0	4,0
126	58	Kalia	Lac	141229	133754	31,2	8,3	708,0	28,0	7,3	76,9	29,4	219,6	25,0	67,0	7,6
127	52	Ngarangou	Lac	144954	133421	30,7	7,8	335,0	32,0	0,0	25,0	10,7	109,8	19,0	10,0	9,0
128	77	Djou I	Lac	142437	135419	31,3	7,5	604,0	48,8	4,4	51,0	13,0	195,2	40,0	25,0	9,0
129	44	konkia	Lac	144741	133245	32,4	7,2	592,0	23,1	0,5	22,9	7,3	73,2	12,0	35,0	12,0
130	55	Dané Koné	Lac	144111	133330	30,6	7,6	267,0	16,0	9,7	25,0	9,9	122,0	12,0	11,0	8,0
131	9	Djigdada	Lac	150937	133339	31,8	8,1	255,0	23,2	0,0	15,0	15,4	73,2	18,0	11,0	6,0
132	67	Maya	Lac	144248	133829	30,8	7,5	723,0	72,0	4,9	45,0	32,0	244,0	35,0	48,0	17,0
133	70	Dodou K.	Lac	144238	133609	30,7	7,5	439,0	28,0	7,3	29,0	16,0	146,4	15,0	12,0	15,8
134	1	Souya	Lac	145848,0	132855,0	31,9	8,6	180,0	16,0	0,0	13,0	3,3	39,0	13,0	10,0	10,5
135	78	Liwa CL	Lac	141600	135158	31,7	8,0	462,0	24,0	2,4	40,0	5,4	97,6	27,0	32,0	13,6
136	79	Doudou Adji	Lac	141550	134534	31,8	8,1	452,0	23,2	1,5	38,0	12,0	97,6	31,0	21,0	3,8

Chad data generated in the framework of the IAEA-supported project RAF/7/011 - isotope data

ID	Latitude	Longitude	Altitude (m)	sampling date	18O (‰)	2H (‰)	3H (UT)	±
Adoumari	13,171944	15,753889	295	2013/07/26	-3,36	-24,4		
Al Bakhas	11,970556	17,073056	316	2013/07/10	-3,81	-27,1		
Ambassatna	12,408611	16,514722	300	2013/07/12	-3,18	-28,9		
Ambatchaye	12,718056	16,531389	294	2013/07/12	-3,91	-31,4		
Amchouraba	11,831944	17,250278	328	2013/07/10	-3,58	-25,0		
Amdogo				2013/07/28	1,41	2,0		
Amsakine	12,881111	16,566389	294	2013/07/12	-3,46	-27,1		
Aradah	12,947222	16,703056	290	2013/07/12	-4,21	-28,7		
Arma				2013/07/26	5,31	27,2		
Bachom	12,85	15,66	290	2013/07/27	0,79	-5,4		
Bisney	12,680278	16,170556	291	2013/07/13	-2,49	-20,5		
Darassalam	12,812222	16,353333	288	2013/07/13	-2,08	-25,2		
Dongoura	12,070556	16,983611	313	2013/07/10	-4,40	-31,2		
Dorora				2013/07/28	1,17	-2,2		
Doulilio	11,915556	16,903611	321	2013/07/10	-3,81	-27,9		
Gama	11,791944	17,164167	328	2013/07/10	-3,36	-21,7		
Gambir	12,532778	16,750278	294	2013/07/12	-2,17	-20,6		
Halloufa	12,486944	16,505000	296	2013/07/12	-2,78	-26,0		
Hille Moustapha	11,915833	17,216111	320	2013/07/10	-4,03	-27,7		
Kara Mallamoudari				2013/07/26	-3,53	-26,4		
Kouka Kermari				2013/07/26	0,21	-5,7		

ID	Latitude	Longitude	Altitude (m)	sampling date	18O (‰)	2H (‰)	3H (UT)	±
Massaakory	12,974444	15,716389	288	2013/07/27	8,45	39,9		
Mouloumari	12,849167	15,653889	291	2013/07/27	4,45	21,7		
Moyto	12,582222	16,560000	293	2013/07/12	-3,18	-25,2		
Nahala	12,018611	16,990278	315	2013/07/10	-4,30	-30,1		
Siridajye	12,466944	16,589722	296	2013/07/12	-2,81	-26,3		
Tourba Ecole	12,870556	15,280000	288	2013/07/28	2,97	8,9		
Lac Chad/Guite	12,903516	14,622910	284	2014/01/22	0,36	2,3		
Amerom	13,353889	15,260556	297,4	2014/02/03	7,84	37,4	5,00	±0.4
Andri	14,058056	14,321389	294,1	29/01/2014	-4,30	-31,5	<0.4	
Bachom	12,845833	15,655000	290	2014/02/05	0,20	-8,4	1,30	±0.2
Bagassola_a	13,533333	14,316944	296,7	2014/01/30	3,82	17,1	3,90	0,30
Bagassola_b	13,534167	14,311667	285,5	2014/01/30	4,19	17,3	3,20	0,30
Bini-Ouara	13,631944	15,487500	296,2	2014/02/01	4,72	20,0	0,60	0,20
Bol	13,475278	14,711389	294,3	2014/01/31	1,29	2,8	14,50	0,60
Boudoukoura	13,602778	14,710556	292,5	2014/01/30	-3,71	-27,2	<0.4	
Boulia	13,433333	15,088889	291,3	2014/02/03	8,00	38,1	3,50	±0.3
Brandal	13,461944	14,815833	292,2	2014/01/31	-4,60	-32,7	4,60	0,40
Daboua	14,408889	13,610556	285,4	29/01/2014	5,93	27,7	<0.4	
Dané-Koné	13,558333	14,686389	289,3	2014/01/31	-4,11	-28,8	<0.4	0,40
Djigdada	13,560833	15,160278	299,2	2014/01/31	-4,49	-30,5	<0.4	
Djou I	13,905278	14,410556	298,7	2014/01/29	-3,40	-26,5	<0.4	
Doum-doum	13,195833	15,386944	285,3	2014/02/03	-4,53	-30,2	1,60	±0.3
Fiérom Daléri	13,671667	15,416944	297,6	2014/02/02	-4,24	-29,0	0,60	±0.2
Forage Am	12,384800	15,042217	296	2014/01/22	-0,84	-9,9	<0.5	

ID	Latitude	Longitude	Altitude (m)	sampling date	18O (‰)	2H (‰)	3H (UT)	±
Goundjo								
Forage Dandi				2014/01/22	-3,35	-26,7	0,90	0,30
Forage Douguia	12,645650	14,824650	287	2014/01/22	-1,32	-5,4	3,40	0,40
Forage Etena	11,931111	15,174222	300	2014/01/23	-2,98	-17,0	<0.5	
Forage Guite	12,902633	14,622600	295	2014/01/22	1,25	6,9	2,10	0,30
Forage Iraque	12,479300	14,964500	288	2014/01/22	-1,11	-10,8	0,90	0,30
Forage Kondoul	11,973639	15,152500	300	2014/01/23	-3,46	-20,4	1,30	0,30
Forage Kournari	11,847972	15,192972	302	2014/01/23	-3,51	-26,9	1,50	0,30
Forage Lougoun/Gana	11,558750	15,148528	311	2014/01/23	-3,30	-17,6	<0.5	
Forage Mailao	11,584817	15,280383	317	2014/01/23	-1,47	-5,9	4,70	0,40
Forage Mandelia	11,729194	15,244778	302	2014/01/23	-4,03	-25,7	<0.5	
Forage Mani-Kosam	12,741167	14,707083	286	2014/01/22	-1,82	-8,7	4,30	0,40
Forage Toukoura	12,032333	15,097278	301	2014/01/23	-3,73	-26,1	<0.5	
Fourkourlom	13,604167	14,134167	294,6	2014/01/29	1,33	2,8	2,60	0,30
Gabdji	14,134444	14,112778	291,5	2014/01/29	2,16	7,4	<0.4	
Galla Sangada I	13,724167	15,258889	318,5	2014/02/02	-4,56	-30,2	4,30	±0.3
Kalérom	13,191111	15,431667	292,1	2014/02/03	-4,50	-29,9	<0.4	
Kalia	13,465000	14,208056	292,9	2014/01/29	3,11	11,0	2,50	0,30
Kermarom	13,688611	15,435556	299,6	2014/02/02	-4,71	-29,5	0,70	±0.2
Kery Kouka	13,119722	15,513056	285,8	2014/02/04	-4,17	-27,5	1,10	±0.2

ID	Latitude	Longitude	Altitude (m)	sampling date	18O (‰)	2H (‰)	3H (UT)	±
Khachkhachaye	12,779444	15,618333	287,9	2014/02/05	0,94	-3,7	0,90	±0.2
Kioua	13,536944	15,393611	296,5	2014/01/31	2,02	3,9	1,10	0,20
kiskawa	14,240556	13,918056	290,9	29/01/2014	1,24	1,6	1,40	0,20
Kondjilia	13,179167	15,458333	287	2014/02/03	-4,12	-27,9	3,80	±0.3
Konkia	13,545833	14,794722	298,2	2014/01/31	-4,18	-31,1	1,20	0,30
Landé	13,651667	15,400833	292,2	2014/02/01	-4,45	-29,8	<0.4	
Leyla Guidi	12,791111	15,563056	287,3	2014/02/04	8,75	40,8	16,60	±0.6
Maar	13,559722	14,507778	286,5	2014/01/30	-1,59	-13,9	<0.4	
Madé III	13,609722	15,333611	302,6	2014/02/01	-4,32	-29,4	0,60	0,20
Madirom	13,483889	14,946111	300,9	2014/01/31	3,29	11,9	3,70	0,40
Malmairi	13,650000	14,139444	291	2014/01/29	3,88	15,3	<0.4	
Massakory	12,974444	15,716667	287,2	2014/02/05	7,90	35,9	<0.4	
Matafo	13,523056	14,683333	285,3	2014/01/31	8,05	34,7	4,80	0,40
Matiou I	14,072222	14,168611	297,3	2014/01/29	0,20	-4,8	0,40	0,20
Mbodou Kaolery	13,185556	15,508889	286,3	2014/02/04	-2,85	-20,7	<0.4	
Méléa	13,530278	14,571944	294,6	2014/01/30	3,75	16,1	1,70	0,30
Merkerom	13,519167	14,732778	292,5	2014/01/31	7,14	33,6	3,30	0,30
Merom Koura	13,475556	14,826111	294,9	2014/01/31	-5,25	-35,3	<0.4	
Ndjaorom	13,474722	15,407778	288,8	2014/01/31	-3,20	-23,7	1,50	0,20
Ngarangou	13,573333	14,831111	300,7	2014/01/31	-3,64	-27,8	<0.4	
Ngodorom	13,594444	14,364167	286,5	2014/01/30	7,43	37,3	0,80	0,20
Ngolio	13,686667	14,597778	296,2	2014/01/30	-4,63	-31,9	1,40	0,30
Ngouri	13,643611	15,368889	301,7	2014/02/01	-4,37	-29,2	0,70	0,20

ID	Latitude	Longitude	Altitude (m)	sampling date	18O (‰)	2H (‰)	3H (UT)	±
Ngourtou I	13,673056	15,381944	308,3	2014/02/02	-4,43	-28,7	1,00	±0.2
Ouné I	13,585000	15,396667	307,5	2014/02/01	1,32	0,5	0,90	0,20
Saouo Boudouma	13,440833	14,752778	297	2014/01/31	1,20	2,4	<0.4	
Souya	13,482222	14,980000	297,2	2014/01/31	-5,02	-34,2	6,20	0,40
Taou Nord	13,541667	14,912778	299,3	2014/01/31	-4,08	-29,6	2,90	0,30
Toutou	13,531667	14,821111	294,8	2014/01/31	-3,32	-24,7	0,80	0,20
Yiri	13,661667	15,281111	304,8	2014/02/01	-4,48	-29,9		
Fleuve Chari/Dougoia	12,639967	14,827467	290	2014/01/22	-0,84	-4,2		
Fleuve Chari/Mailao	11,583883	15,284067	300	2014/01/23	-0,47	-1,6		
Fleuve Lougoun/Gana	11,560515	15,143651	302	2014/01/23	-1,63	-8,0		
Maar Saker	13,508730	14,516946	285	2014/01/30	-0,53	-8,0	0,90	0,20
Polder III	13,563056	14,294722	282,6	2014/01/30	4,97	22,8	2,30	0,30
polder Tchoukou	13,694103	14,097152	277,3	2014/01/29	2,49	8,1	2,80	0,30
Amkoua Sal	13,316667	16,615556	304	2014/04/07	-3,96	-28,4	1,10	0,20
Boudassari	13,412778	16,056944	294	2014/04/07	-4,43	-30,0	<0.4	
Chaddra	13,435833	16,048889	297	2014/04/07	-3,59	-25,4	<0.4	
Diguine 1	13,806667	15,758889	288	07/04/2014	-3,73	-27,9	<0.4	
Fourtchoueskou	13,451111	16,439167	307	2014/04/07	-4,02	-28,2	6,60	0,40
Gara I	13,188889	15,970833	293	2014/04/07	-3,84	-26,9	<0.4	

ID	Latitude	Longitude	Altitude (m)	sampling date	18O (‰)	2H (‰)	3H (UT)	±
Goutchouwo	13,259444	16,385833	307	2014/04/07	-4,31	-29,6	1,80	0,30
Grantessi	13,935000	16,694444	293	2014/04/07	0,71	-2,8	<0.4	
Hissab	13,931667	15,680000	315	2014/04/07	-3,79	-27,9	<0.4	
Kantara	13,602500	17,021111	303	2014/04/07	-4,52	-30,8	<0.4	
Katé-Katé	13,386111	16,012222	290	07/04/2014	-4,42	-29,9	<0.4	
Kokoye 1	13,821944	15,869167	301	2014/04/07	-1,45	-16,2	<0.4	
Koréti	13,280000	16,529167	307	07/04/2014	-4,49	-29,9	<0.4	
Koumagaye	13,506389	16,033333	291	2014/04/07	1,93	6,3	<0.4	
Miché Chada	13,646389	16,428056	298	2014/04/07	-3,54	-27,7	<0.4	
Moussoro	13,644722	16,491111	291	2014/04/07	-4,34	-30,1	<0.4	
Mouzarag	13,288056	15,968611	293	07/04/2014	-3,40	-24,6	3,30	0,30
Ngali Taher	13,914444	15,815000	308	07/04/2014	-3,92	-28,4	<0.4	
Safa Djoula	13,640833	15,831667	300	2014/04/07	-1,77	-19,2	<0.4	
Trawarou	13,283333	16,196111	306	2014/04/07	-4,18	-30,0	<0.4	

Annex 2: Niger data generated in the framework of the IAEA-supported project RAF/7/011

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
YOGO	14,864611	13,792556	313	2013/02/19	233	29,7	6,4	9,4	2,4	20,1	5,9	6,6	31,6	40,0	5,3	-5,66	-35,7	0,3	0,2
LIBOUSS	14,795556	13,794139	318	2013/02/19	208	29,5	6,7	16,0	3,8	23,3	5,5	9,0	33,8	55,0	14,8	-5,86	-35,7	1,2	0,3
DJANDIGA	14,693806	13,728389	317	2013/02/19	263	30,1	6,9	34,9	4,0	23,1	8,1	10,1	37,1	92,0	4,5	-5,87	-37,8	0,6	0,2
LARI KANORI	14,334333	13,191028	291	2013/02/20	1428	29,7	7,4	53,2	70,9	258,1	67,0	47,2	48,8	685,0	0,0	5,50	31,9	0,3	0,2
MANDARA KAÏRAM	14,409222	13,304389	295	2013/02/20	3520	28,3	7,5	114,1	57,5	875,7	103,4	162,4	151,8	1342,0	36,6	7,63	38,0	0,7	0,3
BILABRIN	14,430222	13,414278	298	2013/02/20	1552	27,0	7,8	44,8	34,5	335,7	90,2	50,5	163,9	580,0	68,9	2,17	7,9	3,2	0,2
DORO LELEWA	14,094583	13,457833	295	2013/02/20	2940	27,8	8,2	71,9	14,9	806,2	16,5	62,8	446,7	1007,0	0,0	3,28	13,6	0,7	0,2
DORO LELEWA	14,089927	13,461654	283	2013/02/20	299	33,3	8,2	41,7	11,7	12,7	12,2	2,5	20,9	122,0	3,2	1,37	-2,1	5,6	0,3
KIME GANA	14,240389	13,159528	277	2013/02/21	745	34,1	6,7	37,5	11,2	145,0	17,5	62,8	170,0	145,0	0,0	-6,33	-49,5	0,6	0,3
BARWA	13,879611	13,172444	295	2013/02/21	733	35,7	6,6	25,0	10,0	135,4	14,0	53,1	152,7	122,0	0,0	-6,45	-53,4	0,4	0,3
TCHOUKOU DANI	13,842972	13,200333	302	2013/02/21	798	28,9	7,3	16,8	23,5	106,2	34,4	7,4	9,1	183,0	9,0	7,62	37,7	7,5	0,3
TOUBARAM	13,777639	13,239167	299	2013/02/21	3020	29,3	7,5	27,7	46,5	828,4	52,1	92,8	403,3	1068,0	28,3	4,37	14,8	1,7	0,3
YEBI	13,737528	13,292389	296	2013/02/21	1910	27,1	8,5	30,6	12,6	556,7	25,1	30,6	92,4	1007,0	71,5	5,32	22,7	0,7	0,3
BOSSO	13,700167	13,295556	290	2013/02/22	763	27,3	6,4	23,2	14,9	158,7	17,3	64,7	103,6	183,0	0,0	-5,97	-49,1	0,4	0,2
BLAGANA	13,678444	13,294556	293	2013/02/22	432	26,9	7,5	25,8	10,2	57,3	13,0	13,7	38,0	61,0	22,9	-0,92	-16,0	3,0	0,3
GAMGARA	13,665556	13,272583	297	2013/02/22	711	27,8	7,8	11,5	12,4	140,7	14,7	8,1	1,5	366,0	17,9	-1,30	-16,3	0,9	0,3
ABADAM	13,627222	13,253222	302	2013/02/22	424	28,8	6,5	35,3	11,5	43,7	44,7	19,4	27,0	122,0	20,3	-1,45	-14,8	4,8	0,3
BOULAYI	13,601056	13,230278	300	2013/02/22	695	29,9	8,4	8,1	3,5	150,6	31,9	7,6	8,6	244,0	11,3	-0,83	-13,7	1,6	0,3
DAGAYA	13,555167	13,064333	300	2013/02/22	496	32,6	7,7	24,0	13,7	73,2	17,8	4,7	57,4	128,0	3,1	-2,23	-15,7	3,9	0,3
DJABALAM	13,559167	13,013778	307	2013/02/22	381	28,7	7,6	14,8	7,7	36,0	20,6	8,6	5,5	125,0	6,0	-0,50	-8,6	0,3	0,3
BOUGOUMALOUMDI	13,463944	11,096889	344	2013/02/23	972	28,5	6,3	124,3	37,1	54,1	34,9	90,6	86,4	61,0	383,4	-4,35	-28,7	3,2	0,3
KODJIMERI	13,411778	11,094694	346	2013/02/23	180	30,7	6,2	13,4	4,0	20,3	5,9	6,4	31,1	65,0	0,0	-5,42	-34,5	0,9	0,3
AKAMARI	13,241028	11,114333	340	2013/02/24	150	27,7	6,7	19,2	6,6	12,7	4,9	8,9	16,6	57,0	28,0	-4,34	-30,0	2,0	0,3
MADOU KAOUDI	13,382250	11,130000	339	2013/02/24	242	29,7	6,8	16,3	4,1	31,7	7,0	7,8	41,6	85,0	0,0	-5,78	-36,7	0,2	0,3
N'GUELKAYA	13,425194	11,299861	332	2013/02/24	453	28,2	6,6	46,0	17,8	28,3	8,7	33,5	32,2	61,0	136,3	-4,47	-29,0	1,2	0,3
CHERI	13,422167	11,385917	352	2013/02/24	276	32,3	6,5	29,5	6,2	19,6	10,3	7,5	35,3	61,0	57,8	-3,36	-23,3	0,1	0,2

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
GARGARIRAM	13,221639	11,946250	325	2013/02/25	430	28,9	5,9	50,1	15,7	17,6	12,4	31,2	42,2	45,0	144,6	-2,71	-23,1	4,4	0,3
ABASSIRI PEULH	13,185639	12,032361	319	2013/02/25	4510	29,1	6,8	354,7	74,1	787,5	32,0	399,2	1965,5	61,0	0,0	-5,27	-40,3	1,0	0,3
ABASSIRI	13,160472	12,030778	347	2013/02/25	360	30,6	7,0	27,2	6,3	36,7	8,4	16,3	27,1	31,0	117,9	-3,48	-28,4	4,1	0,3
GADORI	13,145139	12,049500	341	2013/02/25	296	30,9	7,1	30,8	4,1	26,0	4,4	8,0	18,8	61,0	79,6	-3,45	-31,7	1,9	0,3
GOURSOUGOUMIRAM	13,156750	12,078778	334	2013/02/25	267	30,9	6,8	19,8	4,0	36,2	4,1	10,0	49,6	85,0	2,7	-4,86	-41,5	0,8	0,3
N’GAOURIRAM	13,143861	12,080333	332	2013/02/25	552	30,1	6,9	75,2	9,4	44,3	6,5	25,9	103,3	92,0	101,0	-4,33	-30,8	1,1	0,3
YABAL	13,182639	12,065944	330	2013/02/25	651	29,6	6,8	70,1	10,3	56,8	8,6	39,0	117,1	61,0	136,3	-2,88	-24,7	2,9	0,2
KOUBLE MALLAM SIDDI	13,166500	12,129889	326	2013/02/26	152	30,1	7,4	13,9	2,7	16,8	3,0	2,9	24,9	61,0	3,0	-4,17	-27,5	0,5	0,2
TAM	13,134444	12,134944	340	2013/02/26	334	32,1	6,6	27,5	7,6	27,6	7,6	13,4	56,7	95,0	0,0	-3,53	-32,9	0,4	0,3
GREMADI	13,142500	12,168639	332	2013/02/26	692	29,8	6,9	55,7	15,4	57,9	35,4	74,8	44,8	61,0	173,5	-0,05	-7,6	6,1	0,3
DJANDJERI	13,121778	12,274944	330	2013/02/26	175	31,0	7,1	19,6	3,3	18,6	6,4	3,7	1,8	115,0	3,6	0,04	-9,1	4,6	0,2
ABARI	13,106222	12,277694	321	2013/02/26	335	29,3	7,1	40,1	5,3	31,2	15,4	15,3	8,1	122,0	20,1	-0,86	-9,9	4,0	0,3
MARIDI	13,133389	12,301306	321	2013/02/26	242	27,6	6,8	28,8	6,9	17,5	8,1	6,4	4,3	96,0	4,6	-1,08	-18,6	4,8	0,3
BLAMARI KIARI	13,131444	12,325389	330	2013/02/26	313	29,2	6,9	30,3	5,3	21,2	14,1	18,4	24,8	85,0	38,9	-0,75	-15,6	6,2	0,3
KAYAWA	13,307417	12,683917	315	2013/02/27	521	30,4	7,1	25,3	5,4	38,5	58,8	7,3	18,5	153,0	29,9	-1,89	-12,4	3,8	0,3
KOULO KOURA	13,282250	12,669028	312	2013/02/27	877	29,7	7,0	34,4	15,2	135,7	15,3	51,0	52,4	183,0	66,8	-2,90	-17,7	5,1	0,3
DOUROUM	13,326611	12,661806	310	2013/02/27	247	30,0	7,1	42,3	3,7	13,7	7,6	3,1	0,0	122,0	1,9	-0,90	-15,5	0,8	0,2
MADOU KAOURI	13,334972	12,671028	313	2013/02/27	313	30,5	7,1	46,0	4,7	27,4	8,2	27,0	4,7	122,0	6,7	-1,96	-15,5	0,7	0,2
ASSAGA	13,314083	12,707806	310	2013/02/27	269	28,9	2,3	24,5	7,4	26,3	12,4	38,7	12,5	105,0	11,5	-3,79	-23,8	5,5	0,3
CHETIMARI	13,186944	12,423000	314	2013/02/28	644	30,0	7,3	47,1	15,1	29,1	40,3	41,0	56,4	122,0	39,3	-4,53	-31,8	1,6	0,3
WALADA	13,128278	12,487028	323	2013/02/28	424	29,7	6,9	45,4	11,0	29,0	30,3	8,0	8,5	153,0	4,7	-2,21	-19,2	4,6	0,3
MOREY	13,157750	12,466944	324	2013/02/28	205	29,9	6,6	23,5	2,9	18,9	5,5	2,3	6,6	61,0	1,7	-0,37	-8,0	7,6	0,3
COMMUNE URBAINE DIFFA	13,315417	12,612556	330	2013/02/28	925	38,3	6,1	54,9	12,9	157,7	21,7	99,5	167,5	122,0	9,6	-6,08	-43,9	0,1	0,3
ADJIMERI	13,319139	12,598583	316	2013/02/28	443	28,4	7,4	19,0	9,6	36,3	6,2	11,6	9,8	122,0	4,7	-1,41	-13,0	1,9	0,2

Annex 3: Cameroon data generated in the framework of the IAEA-supported project RAF/7/011

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
CMBW1	10,136960	14,172110	443	2013/04/04	667	29,9	5,3	36,1	6,3	92,5	1,6	14,4	26,4	329,4	26,4	-3,75	-19,9		
CMBW2	10,515980	14,233800	436	2013/04/06	315	30,9	6,8	15,6	4,3	47,6	2,7	8,8	5,9	180,6	1,8	-4,66	-26,4		
CMBW3	10,597290	14,289740	405	2013/04/06	184	28,8	6,5	21,6	2,1	21,1	2,0	2,5	5,3	112,2	2,2	-4,29	-22,4		
CMBW4	10,626080	14,305700	426	2013/04/06	294	31,0	6,8	37,3	7,4	23,5	4,6	2,2	2,2	206,2	2,6	-3,59	-19,8		
CMBW5	10,638560	14,303030	437	2013/04/06	547	31,7	7,0	34,5	40,4	40,6	0,4	2,2	9,5	388,0	10,8	-3,76	-22,8		
CMBW6	10,602080	14,310510	400	2013/04/06	1290	30,6	6,8	147,8	46,4	94,6	19,9	120,3	86,6	350,1	260,2	-3,45	-20,7		
CMBW7	10,604790	14,325200	390	2013/04/06	1964	29,6	6,4	189,2	126,3	101,0	14,3	170,9	117,6	479,5	538,1	-3,41	-20,3		
CMBW8	10,619250	14,338550	404	2013/04/06	545	29,5	7,4	47,6	33,1	51,7	1,4	4,7	5,2	369,7	29,4	-4,11	-25,1		
CMBW9	10,610700	14,326820	407	2013/04/06	2400	30,9	6,9	109,8	79,2	214,3	0,7	218,9	75,3	385,5	562,3	-3,06	-19,5		
CMBW10	10,611210	14,326560	411	2013/04/06	2060	29,8	6,8	104,2	67,1	201,6	1,5	239,0	85,0	180,6	478,4	-2,90	-18,5		
CMBW10'	10,610300	14,323290	410	2013/04/06	17	30,8	6,7	1,0	0,7	1,1	0,9	1,6	0,2	4,3	4,0	-3,11	-13,6		
CMBW11	10,745740	14,247180	451	2013/04/07	217	30,4	6,8	19,2	2,9	28,2	0,8	3,6	5,2	100,0	22,8	-3,46	-20,3		
CMBW12	11,049500	14,127450	471	2013/04/07	798	30,8	6,8	65,5	12,0	126,7	0,9	71,7	41,2	292,8	80,0	-3,40	-24,0		
CMBW13	12,072830	15,040470	291	2013/04/08	184	31,6	6,6	21,7	6,2	8,0	2,2	3,0	1,3	109,6	3,0	-2,88	-19,0		
CMBW14	11,045930	14,213100	370	2013/04/09	278	30,1	6,6	35,3	8,1	14,1	12,7	4,4	3,3	195,2	2,2	-4,06	-24,2		
CMBW15	11,043490	14,237410	365	2013/04/09	535	29,8	7,2	40,5	10,7	73,7	0,9	5,3	3,6	361,1	37,8	-5,05	-30,4		
CMBW16	11,045500	14,293320	354	2013/04/09	293	28,3	6,9	34,0	8,8	20,8	1,0	2,0	1,7	211,1	0,8	-5,25	-30,1		
CMBW17	10,986720	14,367770	355	2013/04/09	286	29,5	7,0	40,1	9,4	19,7	6,9	1,6	2,1	201,3	4,4	-5,16	-29,8		
CMBW18	11,043270	14,428800	334	2013/04/09	138	29,3	6,2	14,4	3,4	6,6	5,8	3,1	1,1	80,5	1,9	-5,34	-33,4		
CMBW19	10,925530	14,582400	324	2013/04/09	135	30,6	7,0	15,8	2,1	13,7	1,9	0,6	1,1	87,8	0,2	-4,93	-30,1		
CMBW20	10,809840	14,636840	332	2013/04/09	338	31,1	6,7	38,5	6,3	31,8	3,6	1,7	1,3	235,5	5,5	-4,97	-32,4		
CMBW21	10,743850	14,618220	340	2013/04/09	149	31,1	6,4	18,5	0,1	18,4	1,7	3,1	4,0	83,0	8,9	-3,09	-20,6		
CMBW22	10,627270	14,774250	341	2013/04/09	552	30,5	6,8	75,0	5,6	15,2	2,0	6,4	2,9	292,9	0,8	-6,46	-39,2		
CMBW23	10,434330	14,795880	342	2013/04/09	547	30,4	6,6	40,1	10,7	25,9	4,3	1,7	10,7	203,8	7,5	-5,25	-33,4		
CMBW24	10,349110	15,234160	317	2013/04/09	300	28,0	6,6	28,9	3,8	13,4	33,8	15,6	11,2	115,9	24,4	-4,00	-25,5		
CMBW25	10,325810	15,218630	326	2013/04/09	147	29,8	5,9	16,8	1,3	7,4	8,0	2,8	6,1	71,0	1,8	-4,95	-30,5		

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
CMBW26	10,307990	15,204150	333	2013/04/09	268	30,2	6,1	17,3	3,2	22,8	10,8	9,2	1,1	19,5	101,5	-3,24	-21,0		
CMBW27	10,253780	15,107400	335	2013/04/09	709	29,9	6,88	48,1	29,5	63,1	12,2	12,4	12	364	113,0	-3,90	-26,5		
CMBW28	10,275180	15,027820	336	2013/04/09	391	31,5	6,65	48,9	7,2	22,7	4,5	8,0	11	209	43,6	-4,28	-30,3		
CMBW29	10,185660	14,834370	333	2013/04/09	360	32,2	6,89	17,9	5,0	73,1	0,4	0,7	1	268	0,2	-4,31	-27,5		
CMBW30	10,109010	14,449910	370	2013/04/09	1366	29,8	6,85	118,5	43,8	111,9	2,5	151,5	25	372	202,8	-4,46	-24,2		
CMDW01	6,681590	14,203200	1029	2013/04/03	177	26,0	6,74	19,9	6,4	5,9	4,9	1,5	1	112	0,09	-3,76	-19,3		
CMDW02	6,680000	14,201240	1008	2013/04/03	199	26,0	6,85	38,5	1,7	3,9	6,4	1,9	2	141	0,2	-3,60	-16,8		
CMDW03	10,540630	14,174340	448	2013/04/06	436	29,2	6,58	52,1	6,6	31,0	6,2	34,7	25	153	46,3	-2,88	-14,1		
CMDW04	10,521330	14,199930	440	2013/04/06	658	30,8	6,98	50,5	17,0	110,3	4,8	4,6	14	470	3,0	-5,12	-30,4		
CMDW05	10,594360	14,331480	409	2013/04/06	416	30,9	6,77	48,1	10,7	31,6	6,9	34,3	18	153	70,6	-3,50	-19,3		
CMDW06	10,529208	14,328990	409	2013/04/06	258	31,8	6,58	24,3	6,5	28,2	1,4	11,0	10	115	26,4	-3,16	-18,6		
CMDW07	10,619560	14,338070	412	2013/04/06	578	32,6	6,67	56,1	22,4	39,2	0,2	4,8	5	392	21,0	-4,61	-26,5		
CMDW08	10,603560	14,324840	393	2013/04/06	3600	31,2	6,55	428,8	199,1	157,2	94,5	272,3	197	461	1433,5	-3,82	-22,4		
CMDW09	10,601300	14,324130	408	2013/04/06	417	31,5	6,60	38,2	7,5	16,8	17,9	19,5	16	132	66,7	-3,13	-18,2		
CMDW10	10,574680	14,348320	397	2013/04/06	273	31,0	6,86	28,4	5,2	34,7	0,6	1,9	2	182	2,6	-3,80	-23,9		
CMDW11	10,816610	14,255260	413	2013/04/07	469	32,0	6,60	17,6	4,9	70,8	2,6	8,4	3	244	0,7	-5,03	-29,7		
CMDW12	10,772850	14,272400	415	2013/04/07	215	30,6	5,86	8,0	2,0	34,8	2,7	13,4	12	105	0,09	-4,56	-27,7		
CMDW13	10,786400	14,299250	397	2013/04/07	85	32,0	6,26	5,0	0,8	10,6	3,2	3,0	1	46	2,76	-3,61	-20,5		
CMDW14	11,053320	14,122940	456	2013/04/07	518	34,6	6,89	38,2	9,9	30,2	4,3	24,0	10	165	46,65	-4,11	-25,2		
CMDW15	11,041360	14,117060	473	2013/04/07	327	34,6	6,86	28,1	9,2	45,3	5,8	4,3	5	221	2,65	-3,66	-21,5		
CMDW16	11,393670	14,560040	308	2013/04/07	152	33,2	6,27	7,7	2,5	19,7	5,5	2,3	13	65	1,28	-4,48	-28,1		
CMDW17	11,48542	14,672220	308	2013/04/07	584	32,8	6,46	6,4	2,6	132,1	6,0	21,6	32	318	1,12	-6,87	-50,3		
CMDW18	11,485420	14,673500	308	2013/04/07	855	32,0	6,94	10,8	4,0	210,9	5,3	30,8	43	489	9,93	-5,45	-42,0		
CMDW19	11,683710	14,648570	301	2013/04/07	492	32,5	6,94	32,7	10,8	40,2	6,0	5,8	6	249	0,42	-1,47	-12,6		
CMDW20	11,896060	14,627910	296	2013/04/07	449	31,4	6,90	61,3	8,7	43,0	8,0	5,0	6	311	0,09	-0,32	-9,7		
CMDW21	12,096110	15,015330	301	2013/04/08	128	32,8	6,76	15,2	3,3	9,1	2,2	1,9	2	80	0,09	-3,62	-23,3		
CMDW22	12,101080	15,018360	296	2013/04/08	121	30,5	6,22	8,5	2,7	12,3	1,9	1,1	1	69	0,09	-3,30	-21,5		

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
CMDW23	12,099080	15,022320	290	2013/04/08	158	30,4	6,29	16,9	5,4	12,8	3,4	4,2	3	98	0,15	-3,26	-20,2		
CMDW24	12,079850	15,033220	297	2013/04/08	133	29,6	7,05	15,3	2,7	4,5	1,8	0,4	0	81	0,44	-2,32	-13,3		
CMDW25	12,072500	15,033640	301	2013/04/08	125	31,5	7,23	15,3	3,1	4,7	4,0	2,0	0	78	0,49	-2,97	-15,5		
CMDW26	12,080670	15,018660	289	2013/04/08	305	33,1	6,49	30,1	6,5	20,0	5,0	3,2	26	162	0,09	-3,42	-22,2		
CMDW27	12,177170	14,817310	299	2013/04/08	190	33,0	6,86	25,0	6,3	5,3	12,4	2,2	1	136	0,15	-3,30	-18,5		
CMDW28	12,181180	14,818290	301	2013/04/08	176	33,0	6,64	22,9	3,3	3,5	5,0	1,5	0	109	0,37	-2,90	-16,8		
CMDW29	12,178420	14,814540	298	2013/04/08	237	32,4	7,38	30,9	10,0	7,1	17,2	0,8	1	187	0,18	-2,81	-15,9		
CMDW30	10,045660	14,291280	343	2013/04/09	304	30,7	6,77	37,4	6,7	16,8	13,2	1,3	1	211	0,09	-4,54	-27,8		
CMDW31	11,009660	14,332050	351	2013/04/09	414	30,5	6,86	33,0	8,6	20,4	3,4	2,3	3	188	5,13	-4,94	-30,4		
CMDW32	11,024780	14,458000	324	2013/04/09	507	34,4	6,65	69,8	11,8	9,3	1,6	6,3	2	275	28,57	-4,26	-24,1		
CMDW33	10,974480	14,493290	326	2013/04/09	458	32,0	6,83	62,8	17,5	29,9	2,2	6,1	19	277	45,06	-4,93	-30,8		
CMDW34	10,966060	14,498750	333	2013/04/09	329	31,3	7,10	40,8	15,5	15,8	3,9	5,1	11	207	15,80	-4,93	-29,6		
CMDW35	10,874670	14,65645	320	2013/04/09	413	32,1	6,32	52,9	7,7	23,3	4,4	14,5	23	161	65,39	-4,89	-30,1		
CMDW36	10,843970	14,656450	336	2013/04/09	308	32,2	6,95	26,5	4,4	15,6	5,0	2,5	3	137	2,72	-4,86	-29,5		
CMDW37	10,744690	14,616090	340	2013/04/09	150	32,2	6,18	11,2	4,6	15,7	1,6	2,6	1	87	1,63	-3,40	-19,8		
CMDW38	10,738250	14,607380	336	2013/04/09	153	31,0	6,29	13,1	2,0	13,1	3,6	3,4	2	68	7,93	-3,86	-20,9		
CMDW39	10,408700	14,857710	339	2013/04/09	418	30,7	7,18	45,2	5,0	44,1	3,4	7,3	7	223	61,97	-4,71	-31,5		
CMDW40	10,339900	15,228170	338	2013/04/09	359	29,7	6,03	20,8	7,0	56,7	4,2	23,3	4	120	106,02	-3,19	-21,2		
CMDW41	10,342080	15,231250	321	2013/04/10	466	28,8	6,52	47,5	12,8	36,1	10,3	29,8	1	177	91,47	-2,75	-19,4		
CMDW42	10,347870	15,235390	318	2013/04/10	210	30,4	6,49	23,3	4,9	22,4	5,4	5,1	1	139	0,09	-3,82	-25,0		
CMDW43	10,255330	15,107170	330	2013/04/10	396	30,8	6,55	50,5	11,4	19,2	6,8	1,6	5	275	8,51	-3,77	-24,7		
CMDW44	10,283960	14,925760	343	2013/04/10	410	31,5	6,73	30,9	7,0	15,3	4,9	0,8	5	177	0,09	-1,88	-16,3		
CMDW45	10,230250	14,863110	344	2013/04/10	516	32,4	6,64	67,7	15,1	37,5	5,4	4,1	2	357	2,87	-4,20	-27,1		
CMDW46	10,184560	14,836650	342	2013/04/10	525	30,8	6,83	57,0	14,2	32,3	3,8	1,4	6	354	1,08	-4,38	-30,3		
CMDW47	10,144170	14,795910	345	2013/04/10	507	32,3	6,68	30,5	12,9	21,2	2,3	7,1	3	189	7,95	-2,10	-14,1		
CMDW48	10,146500	14,756610	353	2013/04/10	649	32,6	6,75	53,6	21,4	36,2	1,2	4,0	5	375	9,13	-3,87	-24,7		
CMDW49	10,169460	14,530990	386	2013/04/10	620	32,1	6,98	58,2	19,3	60,8	4,3	4,5	22	451	3,04	-4,13	-24,2		

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
CMDW50	10,112650	14,444350	375	2013/04/10	1781	31,9	6,59	193,8	60,5	126,6	3,9	157,6	21	360	646,15	-3,88	-22,0		
CMDW51	10,118390	14,440020	370	2013/04/10	804	31,8	6,86	59,2	29,4	66,5	4,3	16,2	18	471	23,58	-3,91	-22,4		
CMDW52	10,106490	14,453420	378	2013/04/10	513	33,8	6,79	73,0	9,4	51,6	2,5	3,4	13	311	51,07	-4,11	-20,2		
CMSW1	7,406243	13,548995	1069	2013/04/03	51	22,4	7,04	4,7	2,2	1,6	1,7	0,9	0	31	1,71	-1,89	-7,8		
CMSW2	12,075523	15,039477	290	2013/04/08	72	30,4	7,75	6,2	2,6	4,1	2,7	1,2	0	45	0,76	0,17	-1,9		

Annex 4: Central African Republic data generated in the framework of the IAEA-supported project RAF/7/011

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
GONGUE_katanga4e Ar	6,472700	17,452580	456	2014/07/31	107	28,4	5,8	3,9	10,2	6,4	4,1	3,4	0,01	54,9	11,39	-4,10	-19,1		
BONDILI (Axe NANA BAKASSA 2e Ar)	6,509017	17,455900	470	2014/08/01	118	27,0	6,0	2,3	6,9	10,8	3,2	2,5	0,64	61,0	5,20	-4,10	-17,8		
Lycee Moderne 3e Ar)	6,495617	17,429420	491	2014/08/01	148	28,9	6,1	3,1	14,3	11,5	4,6	0,8	0,01	103,7	0,01	-4,10	-19,5		
BOFANGO (Axe Bouca pK10)	6,463967	17,527470	500	2014/08/01	196	28,6	6,2	4,3	16,6	12,9	6,0	2,0	0,01	97,6	6,08	-4,40	-17,8		
SODECA (Bossangoa)	6,498300	17,424620	504	2014/08/01	179	27,6	6,2	6,0	13,9	11,3	2,6	1,9	0,01	97,6	5,57	-4,20	-20,6		
BODIKI (Axe UA- Bac)	6,444450	17,251480	520	2014/08/02	361	28,3	6,9	9,1	43,1	16,5	6,4	1,8	1,94	213,6	0,01	-3,70	-21,0		
BOALI (Axe UA-Bac)	6,452650	17,361350	492	2014/08/02	277	28,0	6,6	5,9	33,6	14,1	3,8	0,4	1,00	164,7	0,01	-3,90	-20,1		
Bolhome I	7,210317	18,325430	445	2014/11/08	371	21,2	8,0	19,4	31,6	15,9	3,1	0,6	1,52	237,8	0,01	-4,10	-21,3		
Boyo	7,222817	18,319280	444	2014/11/09	179	22,4	6,3	7,9	15,7	7,1	0,9	0,5	0,01	109,8	1,18	-3,40	-18,9		
Boyo	7,216767	18,324020	444	2014/11/09	216	20,6	6,3	10,2	17,0	12,2	2,1	0,4	0,01	140,3	0,01	-4,10	-23,0		
Bolhome II	7,304950	18,282880	430	2014/11/11	159	28,4	5,9	3,0	9,9	13,0	3,4	4,5	0,76	67,1	10,48	-4,60	-20,7		
Sous-Prefecture	7,304350	18,269180	400	2014/11/11	95	29,4	5,7	1,2	6,2	8,9	2,5	1,0	0,01	54,5	0,54	-4,30	-20,4		
Nago 1	7,303056	18,289056	430	2014/11/11	126	29,3	5,8	3,8	9,3	8,6	1,6	0,4	0,01	79,3	0,01	-4,10	-20,5		
Arabe	7,310700	18,298950	418	2014/11/11	114	29,8	5,8	3,8	7,3	10,8	2,7	1,0	0,01	67,1	2,05	-4,00	-20,6		
Bercail	7,309367	18,300130	429	2014/11/11	94	29,9	5,4	1,1	5,9	4,9	0,9	0,7	0,01	18,3	16,86	-4,40	-18,7		
ECAC	7,298567	18,286720	442	2014/11/11	93	29,7	6,0	2,2	6,4	8,9	2,1	0,5	0,01	61,0	0,01	-4,50	-20,3		
Ecole BASSA	7,297883	18,287830	443	2014/11/11	92	29,2	6,0	1,5	5,6	9,7	3,0	0,01	0,01	57,0	0,01	-4,30	-21,7		
Gbakaya	6,880517	18,305220	471	2014/11/14	216	21,2	6,7	3,8	11,2	19,1	2,0	13,1	23,51	58,0	5,34	-3,90	-17,0		
Lenga-Ketté	6,413617	17,434920	516	2014/11/16	214	21,4	6,4	9,0	15,0	14,7	2,8	1,3	0,01	134,2	0,01	-4,10	-18,4		
Koudjou	6,305333	17,449050	527	2014/11/16	131	21,7	6,0	4,7	9,9	8,1	2,8	1,8	0,01	73,2	5,61	-3,80	-16,2		
KANA	6,258950	17,443180	510	2014/11/16	138	21,5	6,1	6,0	10,9	6,7	2,2	0,4	0,01	85,4	3,39	-4,00	-18,0		
GBEKEKOTA	6,193783	17,442330	535	2014/11/16	149	21,4	5,9	6,0	13,1	5,3	0,6	4,3	0,01	54,9	22,62	-3,80	-17,6		
GBAKABA	6,152817	17,438450	556	2014/11/16	134	22,4	6,1	4,3	11,8	9,8	2,8	0,5	0,01	85,4	0,01	-3,90	-18,3		
NDOWKETTE	6,125983	17,435270	600	2014/11/16	134	22,7	6,1	3,9	10,0	10,4	2,9	1,2	1,01	79,3	6,86	-3,80	-16,7		
GONGUE_katanga4e Ar	6,472700	17,452580	456	2015/04/18	123	28,6	6,1	11,0	4,3	7,0	2,8	3,2	0,20	61,0	13,91	-4,20	-18,9	3,0	0,3

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
BONDILI (Axe NANA BAKASSA 2e Ar)	6,509017	17,455900	470	2015/04/18	108	28,8	6,2	7,3	2,3	10,5	2,9	1,4	0,46	64,6	4,43	-4,20	-19,8	3,9	0,3
Lycee Moderne 3e Ar)	6,495617	17,429420	491	2015/04/18	158	29,4	6,3	16,5	3,1	13,1	4,4	0,6	0,21	109,8	0,13	-4,20	-20,3		
BOFANGO (Axe Bouca pK10)	6,463967	17,527470	500	2015/04/18	180	27,3	6,5	16,9	4,2	11,6	4,6	0,7	0,24	111,1	3,57	-4,10	-19,3	3,5	0,3
SODECA (Bossangoa)	6,498300	17,424620	504	2015/04/18				13,8	5,7	10,4	2,5	2,5	0,40	88,4	5,53	-4,00	-19,1	2,1	0,3
BODIKI (Axe UA- Bac)	6,444450	17,251480	520	2015/04/18	360	28,8	7,1	42,4	8,2	16,4	4,2	1,5	0,01	231,8	0,01	-3,60	-21,2		
BOALI (Axe UA-Bac)	6,452650	17,361350	492	2015/04/18	269	28,6	6,8	32,4	4,8	12,4	3,1	1,9	0,91	146,4	0,01	-3,50	-21,4		
Sous-Prefecture	7,305000	18,286611	427	2015/04/16	86	30,0	6,0	6,4	1,1	8,0	3,0	1,1	0,31	51,4	1,19	-4,00	-21,6		
Nago 1	7,303056	18,289056	430	2015/04/16	124	29,5	6,3	9,8	3,9	8,0	1,6	0,0	0,24	77,7	0,27	-3,90	-21,1		
Arabe	7,307722	18,293500	421	2015/04/16	113	29,2	6,3	7,3	3,1	10,2	2,7	0,7	0,21	70,1	1,93	-3,70	-20,2	1,8	0,3
Bercail	7,309367	18,300130	429	2015/04/16	73	31,5	6,0	8,7	0,7	6,0	2,0	0,8	0,37	43,4	7,91	-4,10	-21,1		
ECAC	7,294833	18,285333	427	2015/04/16	91	29,2	6,7	6,8	2,2	8,8	2,2	0,3	0,19	59,3	1,18	-4,40	-22,4		
Ecole BAGGA	7,293667	18,288056	435	2015/04/16	236	29,1	6,9	23,5	10,6	7,4	1,6	2,4	0,48	146,4	1,22	-3,90	-19,1		
Boyo	7,222817	18,319280	444	2015/04/16	36	28,4	5,7	3,8	1,7	2,8	1,8	1,0	0,72	29,3	0,43	-4,00	-19,6		
Boyo	7,220611	18,319000	442	2015/04/16	185	29,0	6,5	16,8	8,2	7,5	2,1	1,3	0,53	109,8	0,73	-4,30	-21,2		
Bolhome II	7,218333	18,322111	445	2015/04/16	219	29,3	6,5	17,9	10,3	12,3	3,2	0,9	0,36	136,6	0,10	-4,50	-23,0		
Bolhome I	7,210317	18,325430	445	2015/04/16	381	27,2	7,0	30,9	19,3	18,2	4,8	2,0	1,22	244,0	0,71	-5,10	-28,0	1,4	0,3
Gbakaya	6,880517	18,305220	471	2015/04/17	601	27,2	7,4	26,7	3,5	88,1	4,0	25,1	86,72	167,1	0,47	-4,10	-19,5		
Lenga-Ketté	6,413617	17,434920	516	2014/04/19	202	27,4	6,7	15,8	9,1	16,2	3,2	1,8	0,47	137,3	0,18	-3,80	-18,3	3,1	0,3
Koudjou	6,305333	17,449050	527	2014/04/19	145	27,9	6,4	12,4	4,8	9,4	4,8	1,9	1,15	91,5	2,35	-4,00	-18,6	3,1	0,3
KANA	6,258950	17,443180	510	2014/04/19	137	27,5	6,4	11,3	6,0	6,7	2,5	0,3	0,34	88,4	1,19	-3,90	-19,0	3,0	0,3
GBEKEKOTA	6,193783	17,442330	535	2014/04/19	135	27,7	6,5	11,8	4,0	9,4	2,5	0,4	0,24	88,4	0,01	-3,70	-17,9		
GBAKABA	6,152817	17,438450	556	19/04/2014	238	28,1	6,8	32,1	2,1	7,8	3,7	0,3	1,91	134,2	0,27	-3,70	-17,3	2,5	0,3
NDOWKETTE	6,125983	17,435270	600	19/04/2014	140	29,2	6,5	11,5	4,3	10,9	4,0	1,8	0,79	85,4	1,86	-3,80	-19,6		
Centre 1 3e Ar)	6,491000	17,439970	480	2014/08/01	81	28,6	5,5	2,3	5,5	4,9	4,8	3,5	1,31	36,6	7,98	-3,30	-13,0		
BOKOTO (Axe UA- Bac)	6,489150	17,121850	546	2014/08/02	176	28,2	6,6	4,3	19,0	3,9	6,6	3,7	0,98	61,0	29,34	-3,90	-18,8		
Bac	7,223233	18,319370	439	2014/11/09	29	20,7	6,2	0,6	2,6	2,2	0,5	0,6	0,01	12,2	3,93	-4,40	-18,0		

SampleSiteName	Latitude	Longitude	Altitude	SampleDate	EC (µS/cm)	T (°C°	pH	Ca	Mg	Na	K	Cl	SO4	HCO3	NO3	18O (‰)	2H (‰)	3H (UT)	±
Cité aerodrome	7,308556	18,302333	427	2014/11/11	50	29,2	5,7	0,6	6,0	2,1	1,2	0,5	0,79	28,2	0,69	-4,20	-19,5		
BOKOTO (Axe UA- Bac)	6,489150	17,121850	546	2015/04/18	138	27,7	6,7	14,0	3,5	4,1	5,7	2,8	0,79	56,4	25,20	-4,20	-20,0		
Bac	7,306278	18,275056	403	2015/04/16	67	29,2	7,3	5,8	2,5	3,6	4,0	1,5	0,01	41,2	0,25	0,20	-1,0		
Cité aerodrome	7,308556	18,302333	427	2015/04/16	22	29,7	5,1	0,8	0,3	3,0	2,0	0,4	0,31	15,2	0,17	-3,60	-20,4	3,1	0,3
GBABORO (KAMO Axe UA- Bac)	6,437067	17,240430	506	2014/08/02	41	26,9	5,6	1,1	3,0	3,2	1,5	0,9	0,01	28,0	0,01	-3,40	-17,2		
GBABORO (KAMO Axe UA- Bac)	6,437067	17,240430	506	2015/04/18	48	27,7	6,1	4,4	1,3	4,1	2,4	1,7	0,77	33,4	0,19	-3,00	-17,7		