LAKE CHAD
SUSTAINABLE WATER MANAGEMENT

Project Activities - Report N° 2
March 2009

Lake Chad Commission

Rond Point de l'Etoile,
N'Djamena

Federal Institute of Geosciences and
Natural Resources

Hannover, Germany

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Report on the BGR Project Activities for the Period September 2008 – March 2009

This report summarizes the project activities performed during the project leader's mission at the LCBC from September 2008 to March 2009. The report presentation took place on the 25th of February 2009 at the headquarters of the LCBC. The main issue of this report is the analysis of the groundwater situation within the Lake Chad basin and especially in the Department of Chari-Baguirmi in Chad.

The BGR project (Federal Institute for Geosciences and Natural Resources) is financed by the BMZ (Federal Ministry of Economic Cooperation and Development from Germany). Its first phase, which was started on Mai 2007, should last for 3 years.

The main objective of the project is to **strengthen the LCBC** so that it is able to **coordinate the exchange of groundwater data** between the member states, **integrate** them **in a management system** and **elaborate sustainable** water resources **strategies**.

1. The Lake Chad basin

The Lake Chad basin has been limited by AHT using HYDRO1K. HYDRO1K is a geographic database developed by USGS to provide global topographic coverage derived from the USGS' 30 arc-second digital elevation model of the world.

Figure 1.1 Lake Chad basin (yellow area) design based on HYDRO1K, a geographic database that provides coverage derived from the USGS' 30 arc-second digital elevation model of the world.

The basin (Figure 1.1) occupies a surface of 2,381,635 km² distributed into the southeast part of Algeria (3,8% of the basin), some small areas of Libya (0,1%), the eastern part of Niger (29%), north-western Nigeria (7,6%), the extreme north of Cameroon (2,1%), the north of the Central African Republic (9,3%), almost the whole of Chad except the extreme north (43,9%), and the Darfur region in Sudan (4,2%).

2. The surface waters

Two main hydrological catchment areas supply most of the water to the Lake Chad. They are the Chari-Logone, which is the most important as it brings about 95% of the annual volume of water that reaches the lake, and the Komadugu-Yobe, which supplies some 3%.

Another supplier is the rainfall. The precipitation on the lake's surface counts for about 2% of the annual volume of water that reaches the lake.

Within the basin there are very important and well-known swamps regions, as the Yaérés in the extreme north of Cameroon, the Lake Chad itself, the Lake Fitri, the Massénya to the south of Chad, the Salamat to the southeast of Chad and the Komadug-Yobe to the north-east of Nigeria (see Figure 2.1).

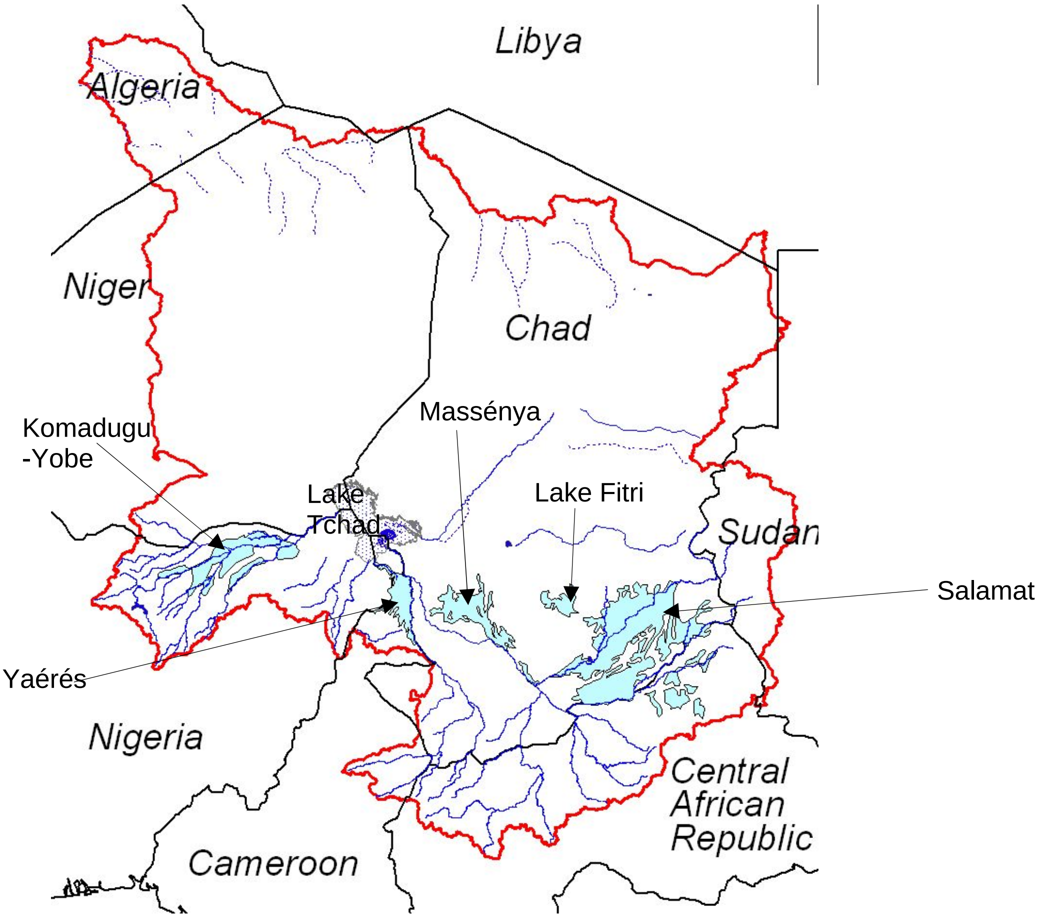

Figure 2.1 Surface water and swamps within the Lake Chad basin.

3. Geology of the basin

Following Figure 3.1 shows the geology of the Lake Chad basin. Most of it is covered by Quaternary sands. Below the sands, at about 75 m depth, appear the clays of the Pliocene with a mean thickness of approximately 280 m (compare with the cross-section represented in Figure 3.2). Further down, a layer of sand of about 30 m thickness is encountered that belong to the Lower Pliocene. These sands give place to the real Pliocene aquifer, as the clays are generally considered as impermeable. Further down appear the sandstones of the Continental Terminal (Tertiary) with a thickness of about 150 m. The deepest aquifer is the Continental Hamadien (Cretaceous), which also consists of sandstone. The basement at the bottom is considered as the base of the system.

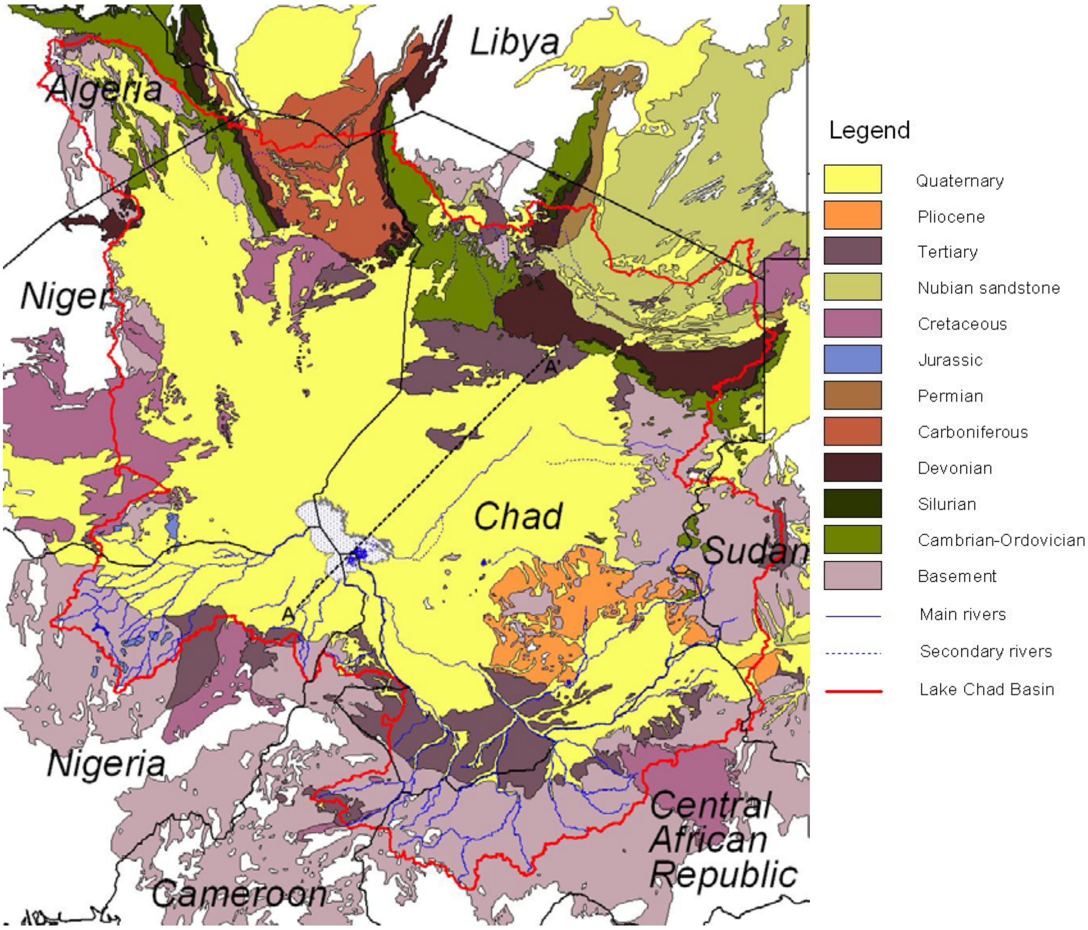

Figure 3.1 Geology of the Lake Chad basin. The next figure shows a cross-section drawn along the line AA'.

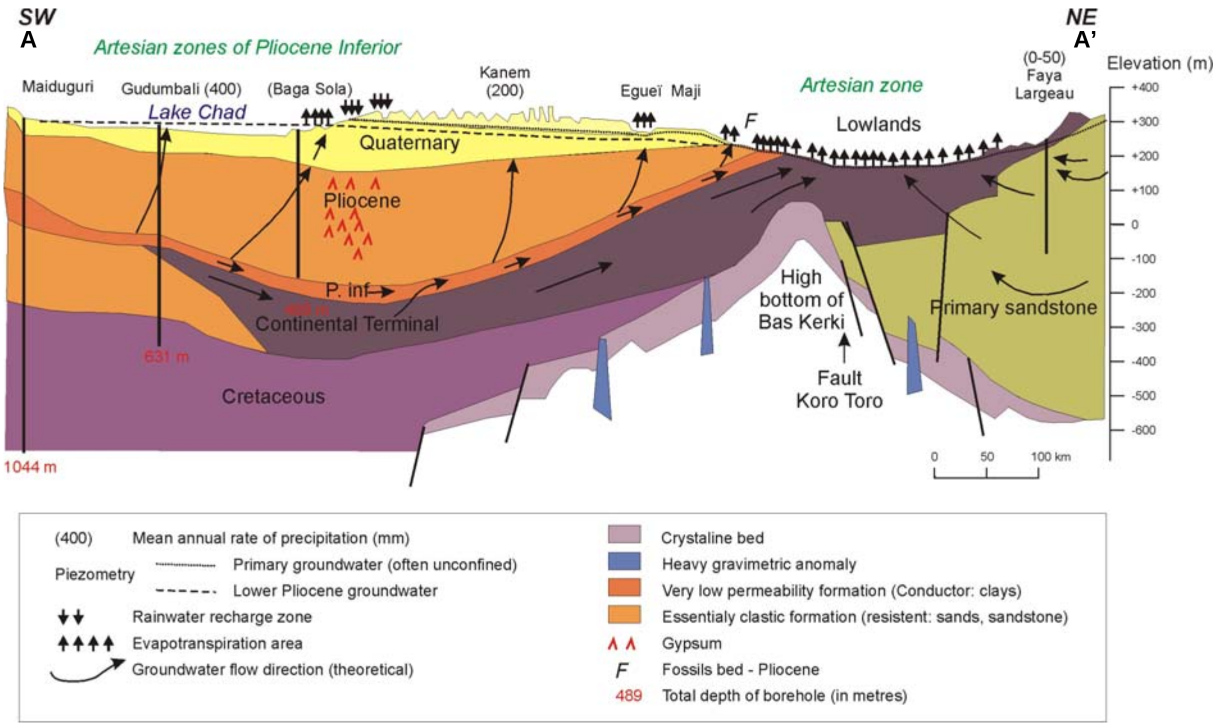

Figure 3.2 Cross-section showing the geology in depth.

4. Groundwater flow in the various aquifers

The groundwater contour line maps based on measurements of rest water levels in wells allow the estimation of the regional groundwater flow.

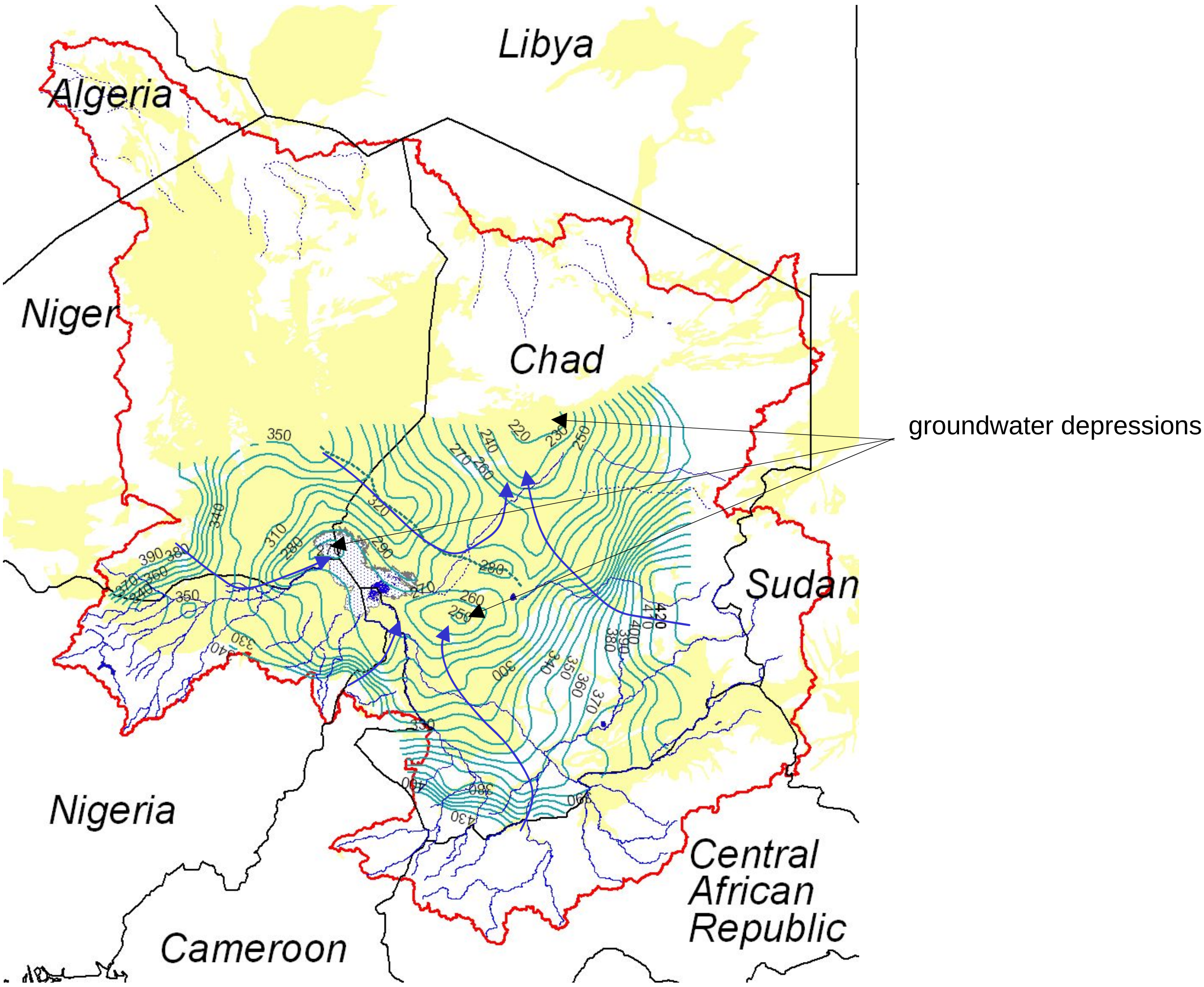

Figure 4.1 Groundwater contour lines for the Qaternary aquifer. They show three main depressions: the first in the Department of Chari-Barguimi (to the south-east of Lake Chad), the second in the Komadugu-Yobe region, and the third in the Pays Bas to the north of Chad. The general groundwater flow direction is indicated by arrows in dark blue.

For the Quaternary aquifer, the groundwater contour lines show the presence of three important depressions in the region, as follows (Figure 4.1):

- Department of Chari-Baguirmi, to the south-east of the Lake Chad.
- Komadugu-Yobe region, to the east of Niger and Nigeria.
- Pays Bas in Chad.

To the south of the basin, the groundwater flows towards the north, so to say towards the lake and the two first named depressions. The northern part of the basin is characterized by the presence of the depression in the Pays Bas that acts as a collector of groundwater flowing from the east (Chad) and the west (Niger). The flow directions are indicated by dark blue arrows in Figure 4.1.

Similarly, the groundwater contour lines for the Lower Pliocene and the Continental Terminal were drawn. Here, it must be bared in mind that available data is insufficient to give confidence to the contour lines. However, they show a general flow direction that should be corrected whenever new data is made available.

Figure 4.2 Groundwater contour lines for the Lower Pliocene. The general groundwater flow direction is indicated by arrows in dark blue.

Figure 4.2 shows that for the southern part of the basin, groundwater in the Lower Pliocene aquifer flows from south to north. However, in the northern part groundwater flows from northwest to southeast.

Figure 4.3 Groundwater contour lines for the Continental Terminal. The general groundwater flow direction is indicated by arrows in dark blue.

In the case of Continental Terminal, groundwater flows always towards the north (Figure 4.3)

5. Research work performed under the umbrella of the BGR project

5.1 Localisation, measurement and sampling of wells

As already mentioned, groundwater contour lines for the Quaternary aquifer indicate the presence of depressions at a regional scale. In order to better understand the genesis of these depressions, investigation works were carried out concerning the Department of Chari-Baguirmi in the Republic of Chad.

A first field campaign of 45 days took place after the rain season (November 2008 to January 2009). It involved localisation, sampling and measurement of rest water level in wells distributed more or less homogeneously throughout the adopted study area (some 15 and 25 km between wells).

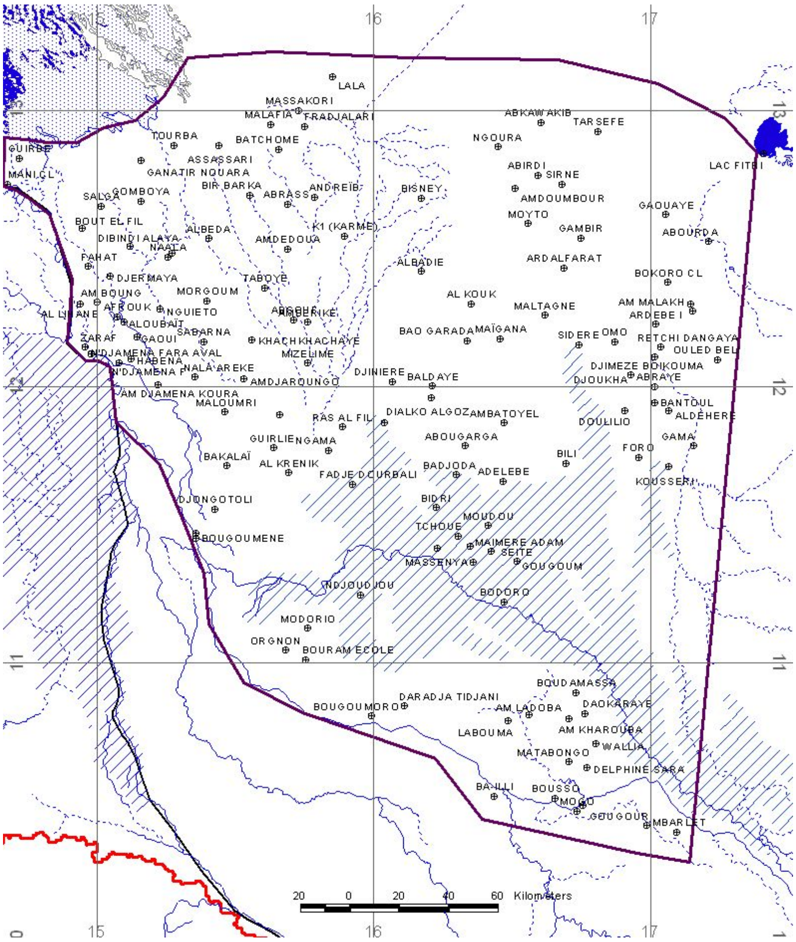

Figure 5.1 Study area adopted to investigate the genesis of the depressions in the Quaternary aquifer. It covers a surface of 55,000 km² in which 136 water points were localised and sampled.

Figure 5.1 shows the study area. It covers a surface of 55,000 km² and belongs almost completely to the Department of Chari-Biguirmi. Although a total of 136 water points were visited, measured, and sampled during the first field campaign, the map shows some empty areas especially in the Massénya swamps towards the southeast, due to inaccessibility during the campaign. They are going to be covered during the next campaign, which should take place at the end of the dry season (March to April). This second campaign will include a new measurement of rest water level and also sampling of those wells that could not be included in the first campaign.

The goal of the sampling is the analysis of water quality (total cations, total anions and trace elements) as well as stable isotope analysis (^{18}O and ^{2}H), all of which will be performed in the BGR laboratories in Germany.

5.2 Results obtained

5.2.1 Depth to groundwater for the Quaternary free aquifer

A map indicating the depth to groundwater for the Quaternary aquifer was compiled using the rest water level data measured in the first field campaign (Figure 5.2).

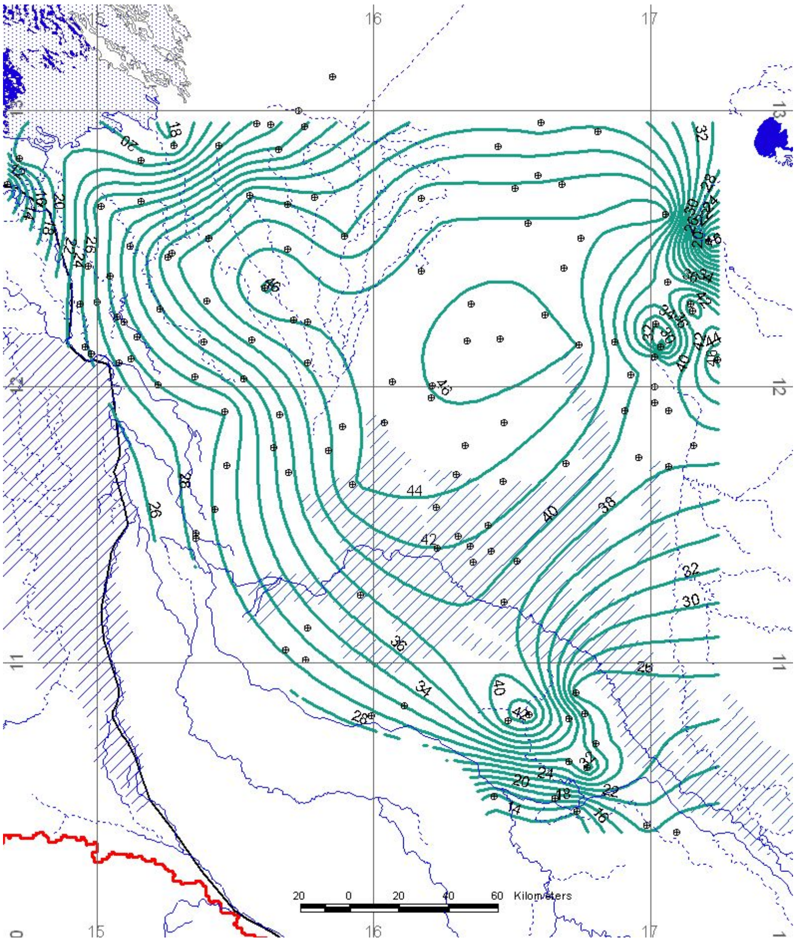

Figure 5.2 Depth to groundwater for the Quaternary aquifer (m below ground).

The map shows that depth to groundwater varies from 15 m under the river Chari to 46 m towards the centre of the study area.

5.2.2 Groundwater contour lines for 1984

A groundwater contour line map for 1984 was produced using the database available at the LCBC (Figure 5.3). As already mentioned in chapter 4, the contour lines reveal a depression towards the north of the study area. Its deepest part is located at a height of 240 m above mean sea level.

It is also possible to distinguish that the Chari River as well as the swamps of Massénya recharge the Quaternary aquifer. In those regions the contour lines show a pronounced curvature.

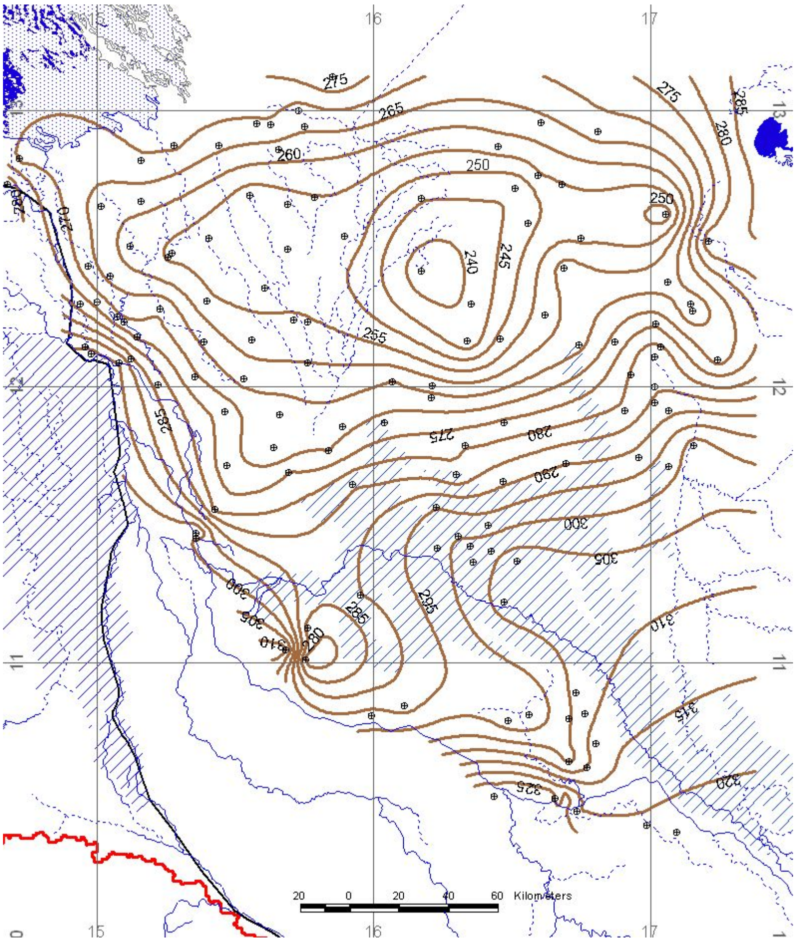

Figure 5.3 Map of groundwater contour lines for 1984 (m above mean sea level). It was compiled using data from the database available at the LCBC. The deepest area has a height of 240 m above mean sea level.

5.2.3 Groundwater contour line map for the period 2008-2009

The groundwater contour line map for the period 2008-2009 (Figure 5.4) was constructed using the measurements obtained during the field campaign. It confirms the presence of the depression, but this time at a lower level (235 m above mean sea level). This depression could be the result of two different effects as:

- Too much extraction, that means overexploitation of the aquifer in the region.
- Enhanced groundwater evaporation in the area. If this is the case, groundwater from the depression should also present a more elevated salt content than groundwater from neighbourhood, especially chloride and sulphate. This effect should be reflected in the chemical analyses.

This map also shows that the Chari River and the Massénya swamps recharge the aquifer, as already explained in section 5.2.2.

A map of annual change in groundwater levels was produced for the period 1984-2008 (Figure 5.5), to be able to analyse the groundwater development in the study area. Whereas the northern part of the study area shows a decrease of water level at a rate of 0,40 m/yr, the region where the depression is located has not experienced any change during the period considered. Opposite to this, an increase of water level is observed for the Massénya swamps (at a maximum rate of 0,6 m/yr) and along the Chari River (at a rate of 0,2 m/yr).

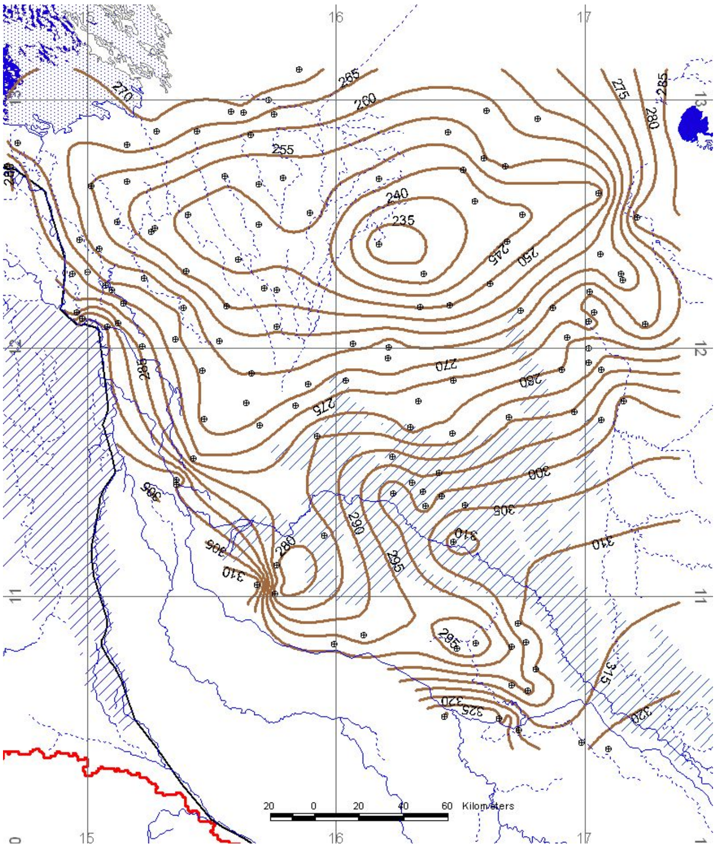

Figure 5.4 Groundwater contour lines for the period 2008-2009 (m above mean sea level). This map was produced using the measurements obtained during the field campaign. The deepest point is at a height of 235 m above mean sea level.

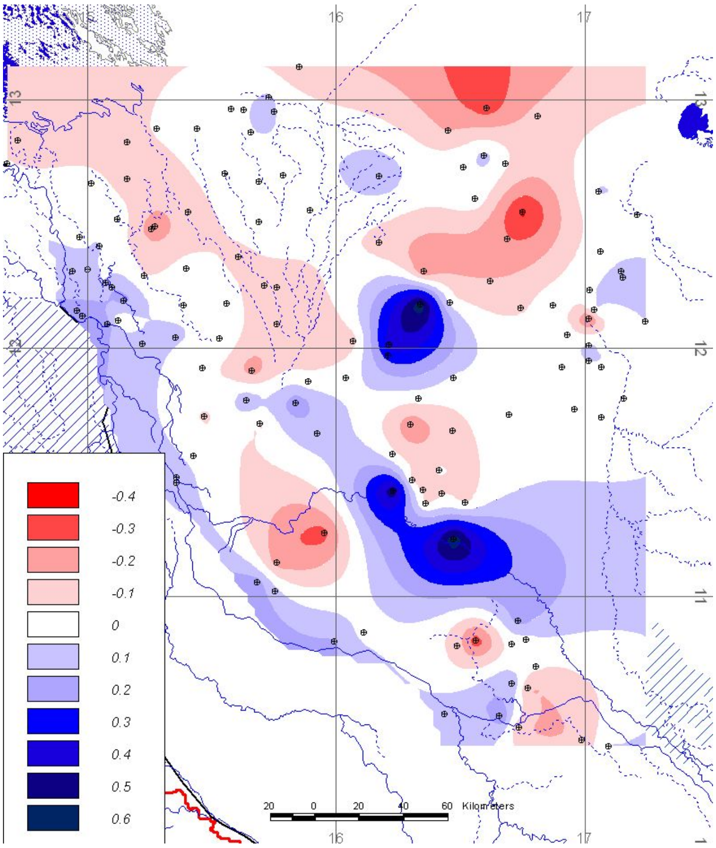

Figure 5.5 Annual changes in groundwater levels for the period 1984-2008.

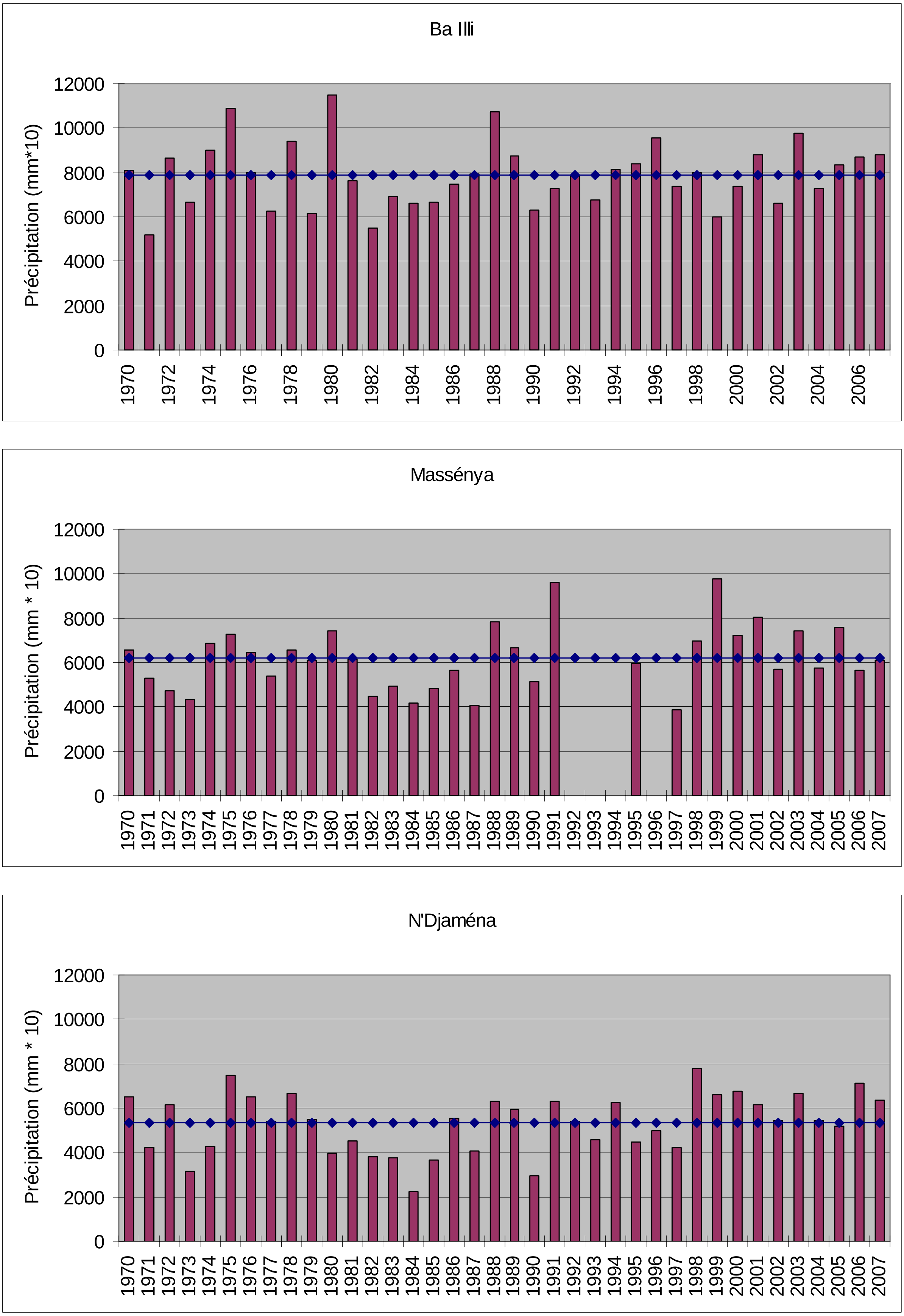

Figure 5.6 Annual precipitations measured by the “Water Resources and Environmental Direction” (DREM) for three stations located within the study area. The blue line indicates the average for the period 1970-2007.

The increase of water levels below the surface water bodies is probably due to an enhanced precipitation during the period considered. From the mid 80's the region has been suffering many years of drought, but since the beginning of the new century the precipitation has increased to even overcome the average of the last thirty seven years (Figure 5.6). The swamps as well as the flood planes of the Chari River get more water and thus, there is more water available for recharge of the aquifer. However, a justification for the decrease in water levels for the areas far from surface water bodies must be found. An explanation could be that the recharge in these regions, even with enhanced precipitation, is still less important than the evaporation.

5.2.4 Hydrogeochemistry

The chemical analyses allow for a characterisation of groundwater and thus of the different aquifers. Waters close to the recharge zone have a weak mineralisation, similar to that of precipitation. But during flow in the underground, groundwater absorbs the minerals available in the environment. Therefore, samples taken from a region far from the recharge area would always show higher mineralisation, reflecting the minerals available in the rocks of the underground.

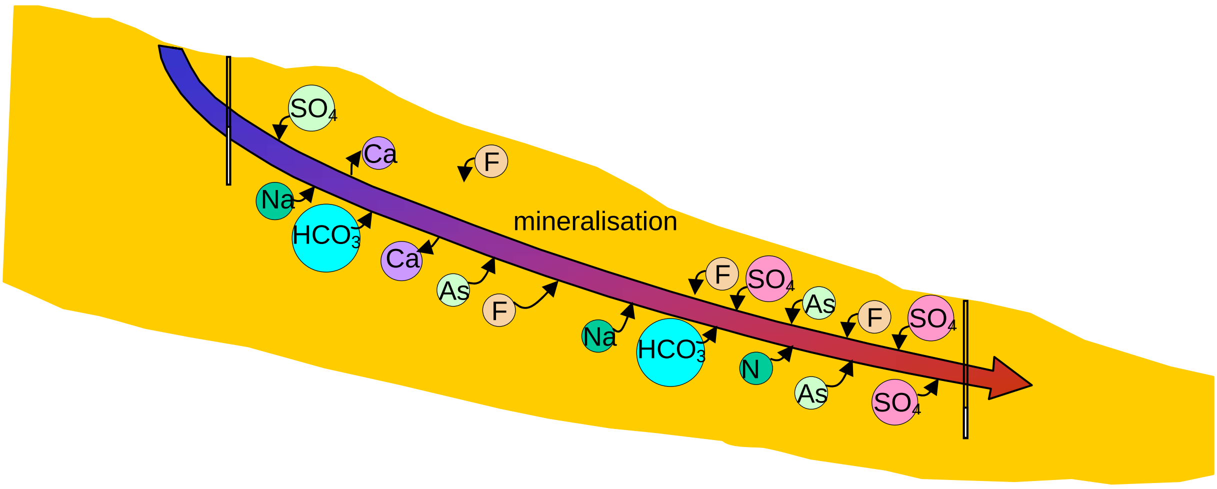

Figure 5.7 Groundwater mineralisation during the flow in the underground.

As already mentioned, all 136 water points visited during the field campaign were sampled. Due to the fact that 122 of them were hand-dug wells with a diameter of 1.5 to 2 m, samples were taken from the bucket used for water extraction. Other 3 samples belong to drilled wells that extract water from the Lower Pliocene. Eleven samples were taken from surface water: Lake Fitri (1) and Chari River (10). The in-situ measurements included:

- pH.
- Electrical conductivity.
- Water temperature.
- Total alcalinity.

All samples were sent to the BGR laboratory, Germany, for analysis (total cations and anions, trace elements). The next paragraphs explain with more detail the results from the chemical analyses.

Piper Diagram

The Piper diagram presents three areas defined by waters of very different characteristics. If the analysis falls in the sector defined as "bicarbonate calcium", it means that the water is weakly mineralised, in other words, it belongs to a zone located nearby the aquifer recharge area. Surface water, if originated by precipitation, should show this quality.

The sector named "bicarbonate sodium" is defined by waters that were recharged relatively long ago and have flown a certain distance within the aquifer to allow for sodium to replace calcium. These waters have a stronger mineralisation.

The sector indicated as "hyper-chloride sodium" (also "sulphate chloride sodium") shows waters with high mineralisation. They are located far away from the recharge zone and have flown a long distance in the aquifer. In this process, bicarbonate has been replaced by sulphate and chloride is added to sodium.

The arrow in the figure shows the direction of mineralisation – from blue to red – or from bicarbonate-calcium to hyper-chloride sodium through bicarbonate-sodium.

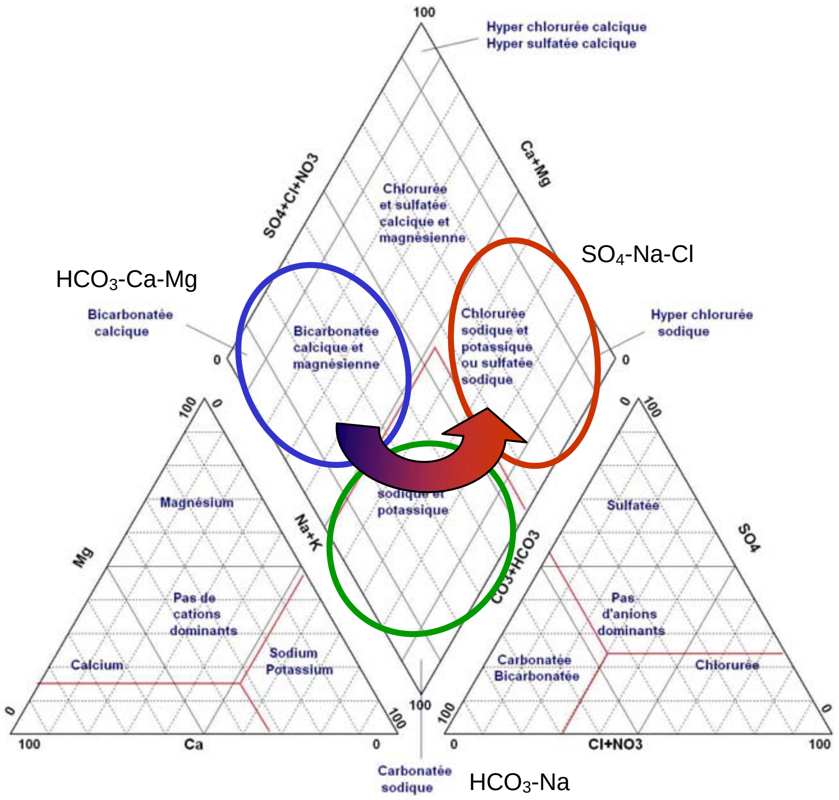

Figure 5.8 Piper diagram for explaining water quality.

Figure 5.9 shows the location of the sampling points (a) and the Piper-diagram with results obtained (b) for all eleven surface water samples. As already explained all of them indicate waters of bicarbonate-calcium type and are thus originated by local precipitation.

When drawing the same Piper diagram for groundwater samples, the representation is quite different (Figure 5.10). Although most of the samples indicate the presence of groundwater of bicarbonate-calcium type, also waters of bicarbonate-sodium type appear and even waters of sulphate-chloride-sodium type.

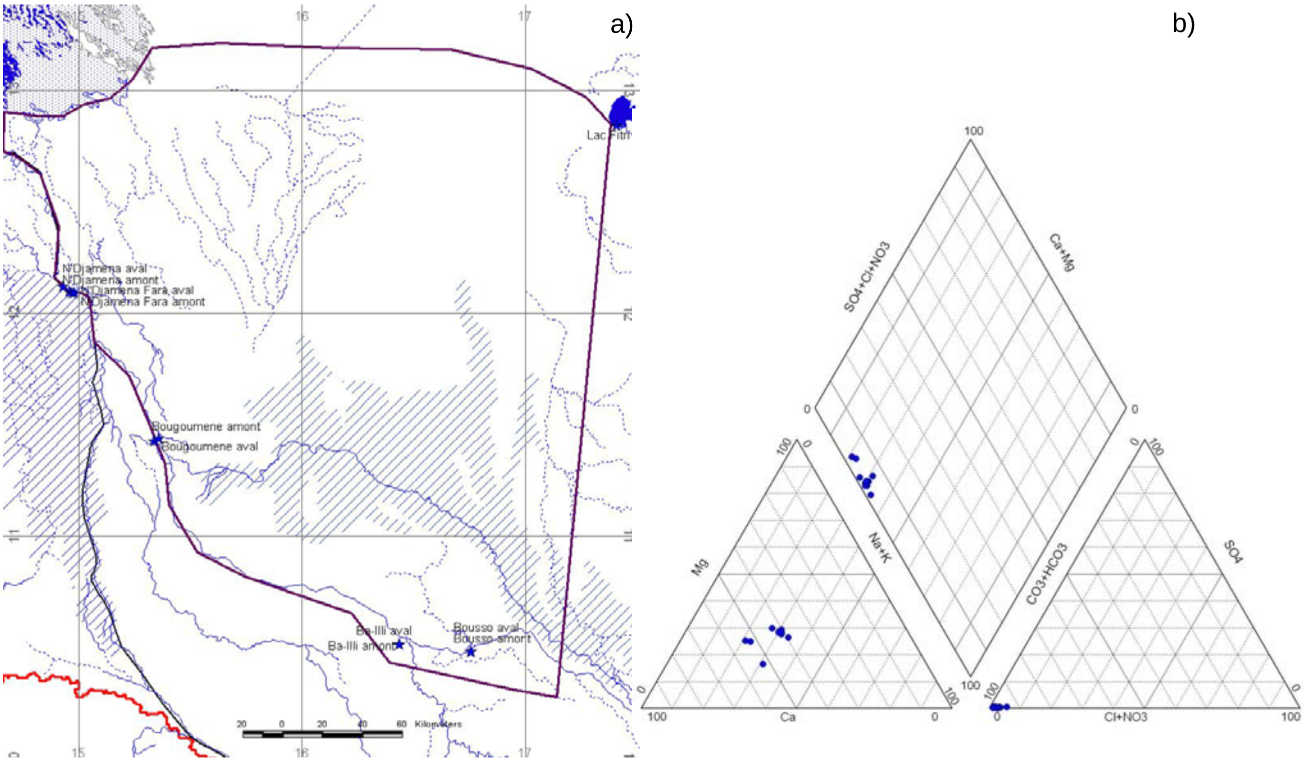

Figure 5.9 Water points sampled during the field campaign (a) and chemical analyses results (b) for surface waters (BGR laboratory).

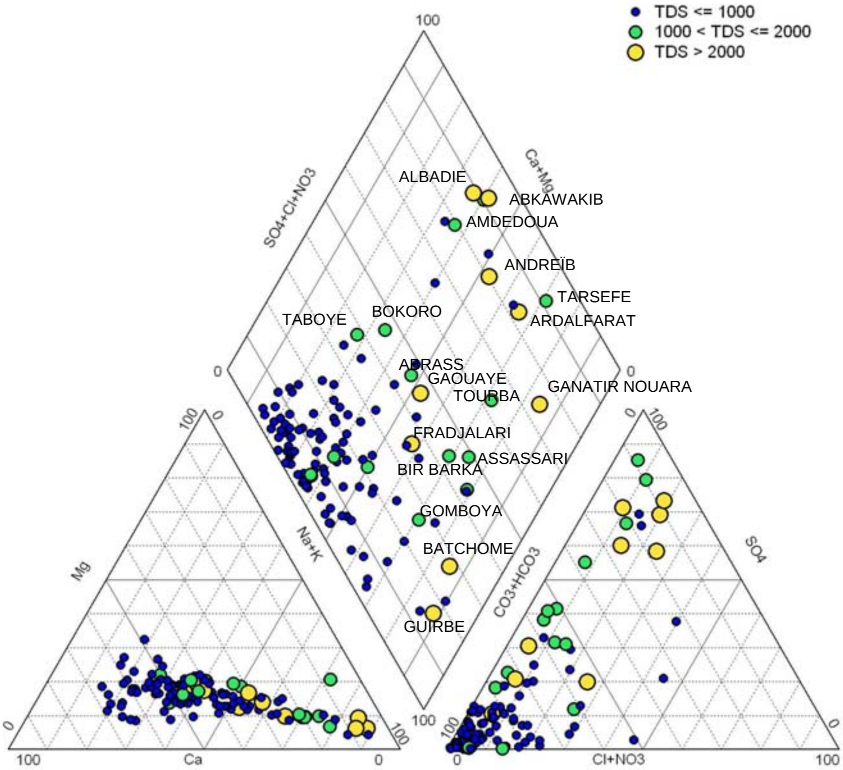

Figure 5.10 Chemical analyses results for groundwater (BGR laboratory).

The Figure 5.10 also shows that there are different concentrations of total dissolved solids (TDS) that means different salt contents. The waters with the higher salt content belong to the region where the groundwater depression is found.

According to the World Health Organisation (WHO), TDS concentrations higher than 2000 mg/l characterise waters that cannot be used for human consumption, as the salt content is too high. However, waters with TDS concentrations up to 5000 mg/l can still be used for livestock supply. If TDS concentrations are higher than 5000 mg/l, then the waters cannot be used for supply at all.

Electrical conductivity

The electrical conductivity distribution map (Figure 5.11) indicates a low conductivity (200 µS/cm) along the river Chari and the Massénya swamps, which is typical for groundwater recently recharged. On the contrary, to the north of the study area where the groundwater depression is located, a very high conductivity is encountered (up to 5000 µS/cm).

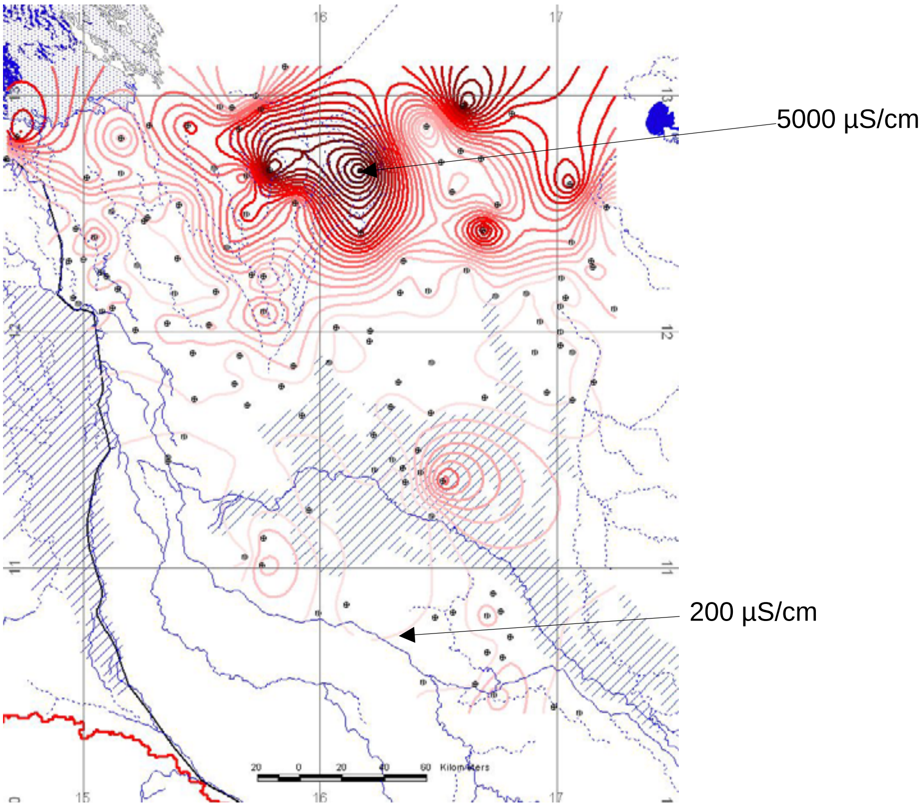

Figure 5.11 Electrical conductivity map (µS/cm). Groundwater to the north of the study area show very high conductivity, while close to the river Chari and the Massénya swamps the conductivity has values typical for recently recharged waters.

A high conductivity indicates the presence of salts, which can be caused by:

- Evaporation, because only the water molecule suffers the evaporation process while the salts remain on the soil. In this case, also high chloride and sulphate concentrations should be encountered in soil towards the north of the study area.
- Stagnant water, in which case the high salt content is due to the ion exchange with the underground. As groundwater does flow extremely slowly, it has enough time to absorb minerals from the surrounding environment. In this case, the isotopic analyses will show "old" water or, in other words, water that has been recharged long time ago.

Chloride

The chloride map (Figure 5.12) shows a distribution very much similar to that of electrical conductivity. Therefore, it is concluded that high conductivities are due to the presence of high chloride concentrations, which in terms confirms the hypothesis of enhanced evaporation in the northern part of the study area.

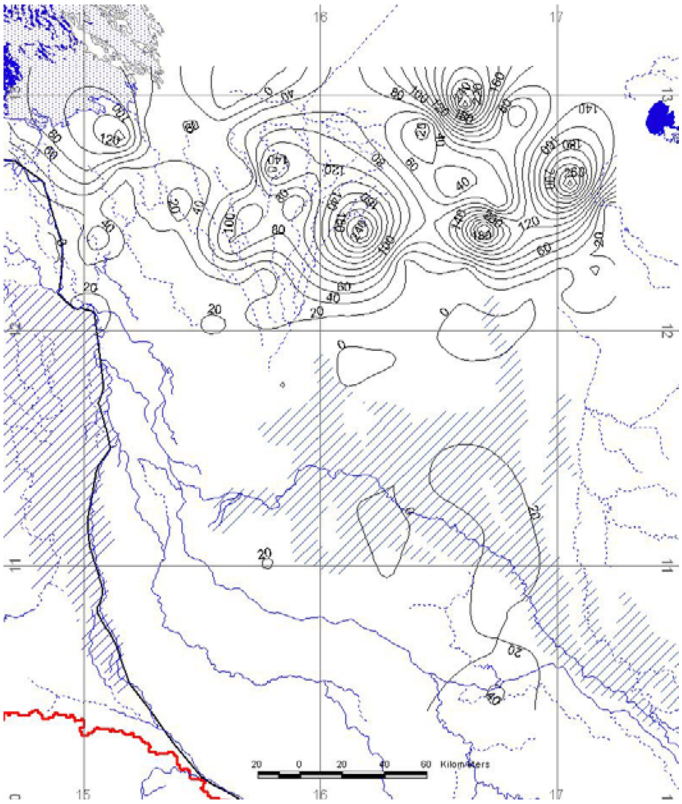

Figure 5.12 Groundwater chloride distribution map (mg/l).

Sulphate

Similar to the chloride map, the sulphate map (Figure 5.13) shows a high concentration in the northern part of the study area caused by enhanced evaporation.

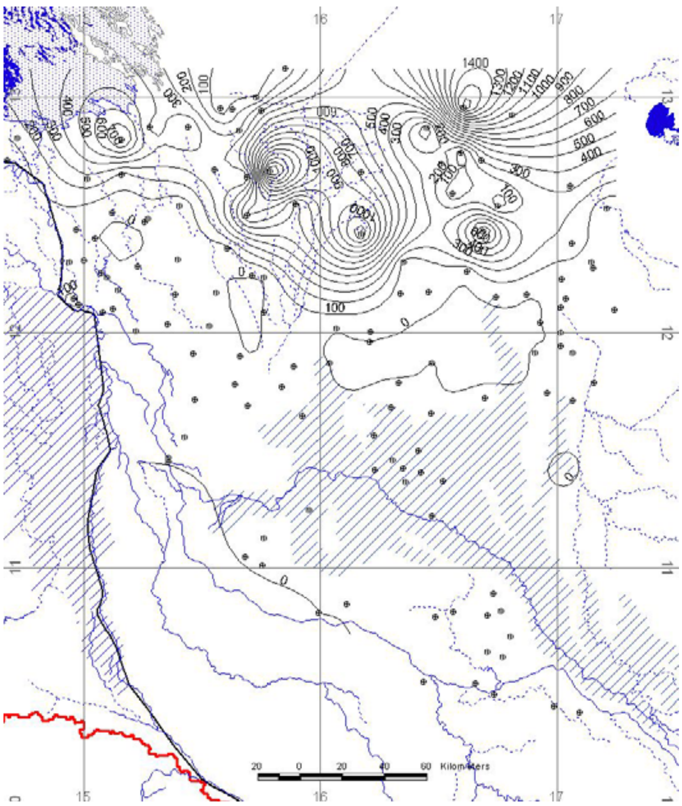

Figure 5.13 Groundwater sulphate distribution map (mg/l).

Nitrate

Nitrate is generally an indicator of groundwater contamination, mostly caused by inadequate use of nitrogenised fertilizers, by inefficient or defect sanitation plants, or even by direct pollution with human or animal faeces.

High nitrate concentration is considered as carcinogen for adult persons, if exposure is permanent. It is also known as the cause for the so called "blue death" of babies, due to lack of oxygen in blood. For this reason, the upper limit accepted by the WHO norms (and also EU and EPA in the USA) is fixed at 50 mg/l (expressed as nitrate NO_3^-). However, the EU norms consider a concentration of 25 mg/l as the figure from which measures of groundwater protection should be adopted.

The black circles in Figure 5.14 indicate those wells in which the nitrate concentration is much higher that the limits given by the norms (maximal measured concentration of 353 mg/l). However, these are point contaminations, due to the way in which the wells are utilised. The drinking troughs for the animals are located next to the well therefore, the area surrounding the well is contaminated with their faeces. To extract the water, a bucket hanging from a cord is used, which is pulled by a bull. Whenever the cord falls on the ground it gets contaminated with dirt and the faeces that will fall into the water when the bucket is pulled into the well.

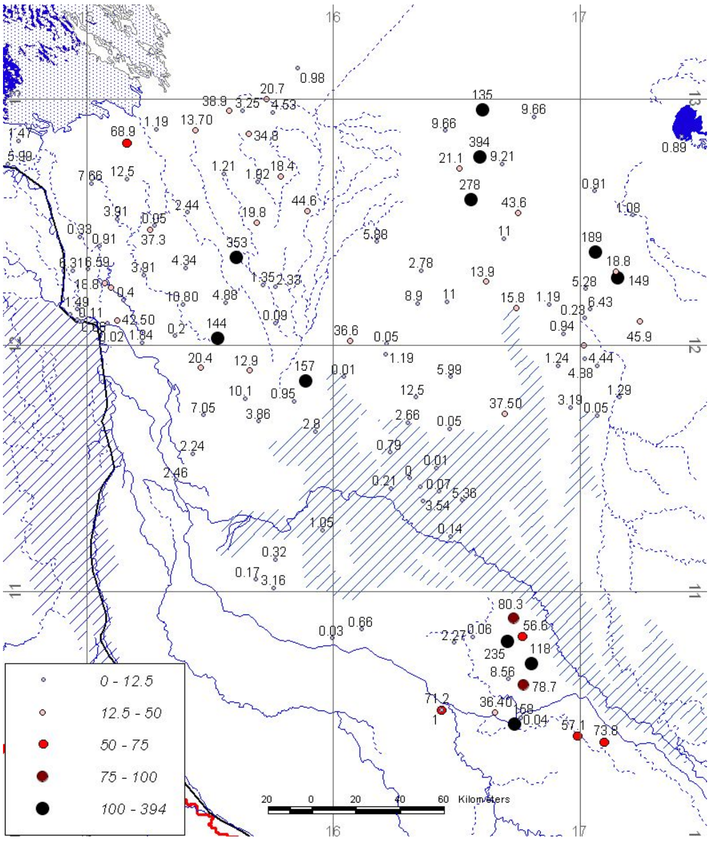

Figure 5.14 Groundwater nitrate concentrations (mg/l).

Fluoride

Groundwater in the study area also shows fluoride contents above those allowed by the WHO norms, which upper limit is fixed at 0.5 mg/l (Figure 5.15).

Fluoride can have two different sources:

- (Fluor)Apatite ($Ca_5[(F,Cl)(PO_4)_3]$.
- Fluorite (CaF_2), which often appears in volcanic rocks and sediments.

Should the source be apatite, then groundwater should also show high contents of phosphate. As it is not the case (compare Figure 5.16), it can be concluded that rather fluorite is the source of fluoride in groundwater.

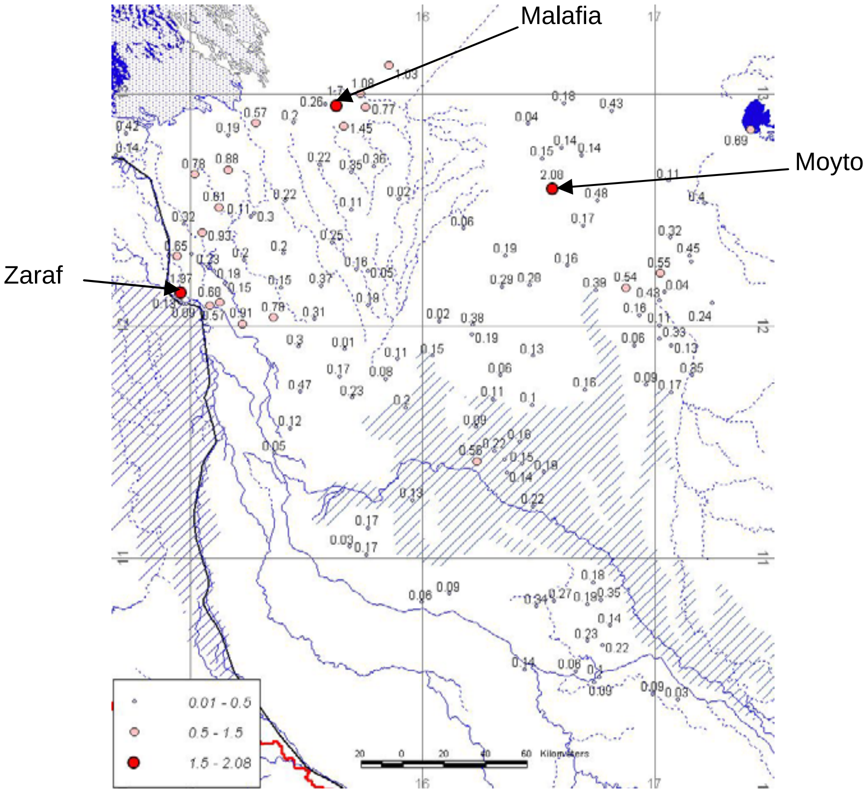

Figure 5.15 Groundwater fluoride concentrations (mg/l).

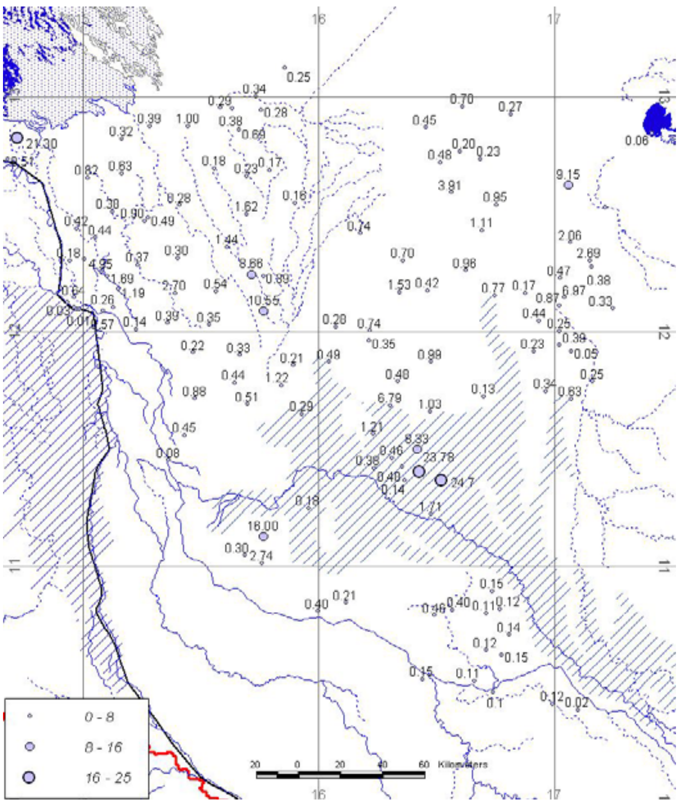

Figure 5.16 Groundwater phosphate concentrations (mg/l).

6. Summary and conclusions

The groundwater depression located within the Quaternary sands to the north of the Chari-Baguirmi Department has been investigated more in detail in order to understand its genesis. The study area is limited to the north by the 13° parallel and to the east by a straight-line from Lake Fitri to the town of Mbarlet south of the Chari River. The Chari River represents the southern and western limits. The Massénya swamps inundate the study area from the centre to the south-eastern corner (Figure 5.1).

A 45-days field campaign took place from November 2008 to January 2009 (short after the wet season) during which water levels in 136 water points were measured and groundwater sampled for complete chemical analyses and isotopic studies. The chemical analyses were performed in the BGR laboratories in Germany. Unfortunately, isotopic analyses have not finished yet and therefore no results can be included in this report.

The water level measurements allowed the compilation of a groundwater contour line map for 2008-2009. It shows higher level of groundwater along the Chari River and the Massénya swamps, which according to the chemical analyses have a weak mineralisation. Therefore, it can be concluded that both the Chari River and the Massénya swamps recharge the Quaternary aquifer, at least short after the wet period.

The groundwater contour line map also shows the depression with its deeper point at 235 m above mean sea level. Here, groundwater quality presents enhanced salt content. These two effects together indicate that the depression is caused by enhanced evaporation from groundwater, which certainly overcomes whatever recharge from precipitation can take place. Evaporation takes place probably through the palaeo-delta sands of the Chari River.

Groundwater quality is good enough to be used for human consumption. However, a wrong management of the wells used for watering livestock that allows animal faeces and dirt enter into the well leads to a localized and direct pollution of groundwater. This is indicated by the presence of very high concentrations of nitrate (up to 353 mg/l). It is recommended that a better well management is implemented to avoid that the local pollution becomes a regional hazard. Further, there low concentrations of fluoride are encountered in groundwater samples due to the presence of fluorite in the underground.

Surface water presents a very weak mineralisation, which indicates that they are produce of precipitation, at least short after the wet season.

Bear in mind that some of these conclusions might change with the results of the field campaign presently ongoing.