Lake Chad Basin:
Sustainable Water Management

Groundwater Chemistry and Quality of the Northern Lake Chad Region, Republic of Chad

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Summary

In the last years the Lake Chad Region has experienced a serious humanitarian crisis due to the Nigerian refugees fleeing from Boko Haram. People face food insecurity and malnutrition and they lack access to water in adequate quantity and quality as well as basic hygiene services. Groundwater is the most important source for water supply and its quality with respect to human consumption is of high priority. This reports summarises analysis results from hydrochemical investigations of ground and surface water concerning drinking-water quality from samples taken in the northern depression and along the former northern Lake Chad shoreline (1963 extend) on the Chadian side. Groundwater quality is evaluated concerning the WHO (2011) guideline.

The sampling campaign was conducted between 07.02.2017 and 14.02.2017 and a total of 63 samples were taken: 62 from groundwater and one from surface water. The water samples were analysed at BGR laboratories for stable isotopes, total ions and trace elements. In-situ pH and electrical conductivity of all collected samples were measured using a handheld WTW Multi 3430.

The majority of the sampled groundwater is not suitable for drinking-water purposes as 38 out of 63 water samples have a chemical composition that does not meet the WHO recommendation. Considering other limitations, e.g. high sodium or sulphate concentrations, only five out of 63 samples are suitable for drinking-water purposes.

Improved protection of groundwater with appropriate measures may solve only some of the quality aspects in the study area. Problems associated with the dissolution of specific ions in water during infiltration, percolation, and groundwater flow may not be solved using the common measures of drinking-water protection. To overcome these problems, identification of other sources of drinking-water might be appropriate.

Other alternative drinking-water resources could be the deeper parts of the phreatic Quaternary aquifer or the confined aquifer of the lower Pliocene and Miocene (Continental Terminal) deposits, depending on their individual appropriateness concerning drinking-water quality.

Keywords: Lake Chad Basin, groundwater quality, stable isotopes, drinking-water

1. Introduction

The program “Sustainable Water Management of the Lake Chad Basin” is a technical cooperation program between the Lake Chad Basin Commission (LCBC) and the Federal Ministry for Economic Cooperation and Development (BMZ). The program consists of three different components: “organization development” and “climate change adaptation” performed by the Gesellschaft für international Zusammenarbeit (GIZ) and “groundwater management” executed by the Federal Institute for Geosciences and Natural Resources (BGR).

Groundwater is the most important source for water supply in the Lake Chad Region and its quality with respect to human consumption is of high priority. In order to improve the knowledge of the LCBC regarding groundwater characteristics and quality in the Lake Chad Basin, the project has conducted several field campaigns in different areas of the Lake Chad Basin.

In recent years the Lake Chad Region faces a severe humanitarian crisis. The already precarious living conditions of the majority of the population has been aggravated by the arrival of more than 100,000 refugees fleeing the terrorist group of Boko Haram, especially active in northern Nigeria (UN OCHA, 2017). To provide the local and displaced people with access to water with a minimum standard of quality and quantity is an essential element of the humanitarian aid in the region. However, the particular geological, hydrogeological, and climatic context of the region leads to specific groundwater quality problems that reduce the rate of access to water for human consumption. Little is known by the regional humanitarian actors about the source of the water quality problems. The aim of this study, that took place in February 2017, is to contribute to the knowledge about water quality in the Lake Chad Region.

The present report presents the results of this campaign in the northern basement and along the northern shoreline (extend from 1963) of the Lake Chad. This report summarises results from hydrochemical investigations of ground and surface water regarding drinking-water quality.

Details about the methodology of the field campaign are described in Serele et al. (2017). In total 63 water samples were collected: 47 groundwater samples from drilled wells, 15 groundwater samples from hand-dug wells, and one sample from surface (lake) water. During the field campaign, pH, electrical conductivity, and temperature of each collected water sample were measured in-situ. The water samples were analysed at the BGR laboratory in Germany for complete anion and cations as well as for trace elements and stable isotopes (^{18}O, ^{2}H).

Objectives of this report are:

- Classify water quality for human consumption considering the World Health Organisation guidelines (WHO 2011)
- Improve understanding on spatial distribution of groundwater chemistry
- Recognise spatial patterns of groundwater quality
- Identify recharge processes
- Give recommendation concerning possibilities to improve water supply

2. Study Area

2.1 Geography

The study area is situated in the Republic of Chad and extends at the northern part of the Lake Chad (shoreline extend from 1963) in the Départements Fouli and Kaya between longitude 13.4° and 14.1° East and latitude 13.4° and 14.5° North (Figure 1). The elevation varies between 260 m and 307 m. The highest elevation are present along the former northern shoreline of the Lake Chad and the Great Barrier in the south of the study area. Lowest altitudes correspond to the central western part around Yakou. The semi-dessert landscape is characterised by sand dunes of some 10 m height striking in NE-SW direction. The interdunal valleys are occupied by seasonal rivers (wadis). The vegetation in the study area is a thorny steppe. Predominantly scrubs (i.e. Leptadenia Pyrotechnica) are found. In the wadis also other bushes (i.e. Salvadora Persica, and Calotropis procera) and palm trees (Borasus Aethiopium, and Phoenix Dactylifera) occur.

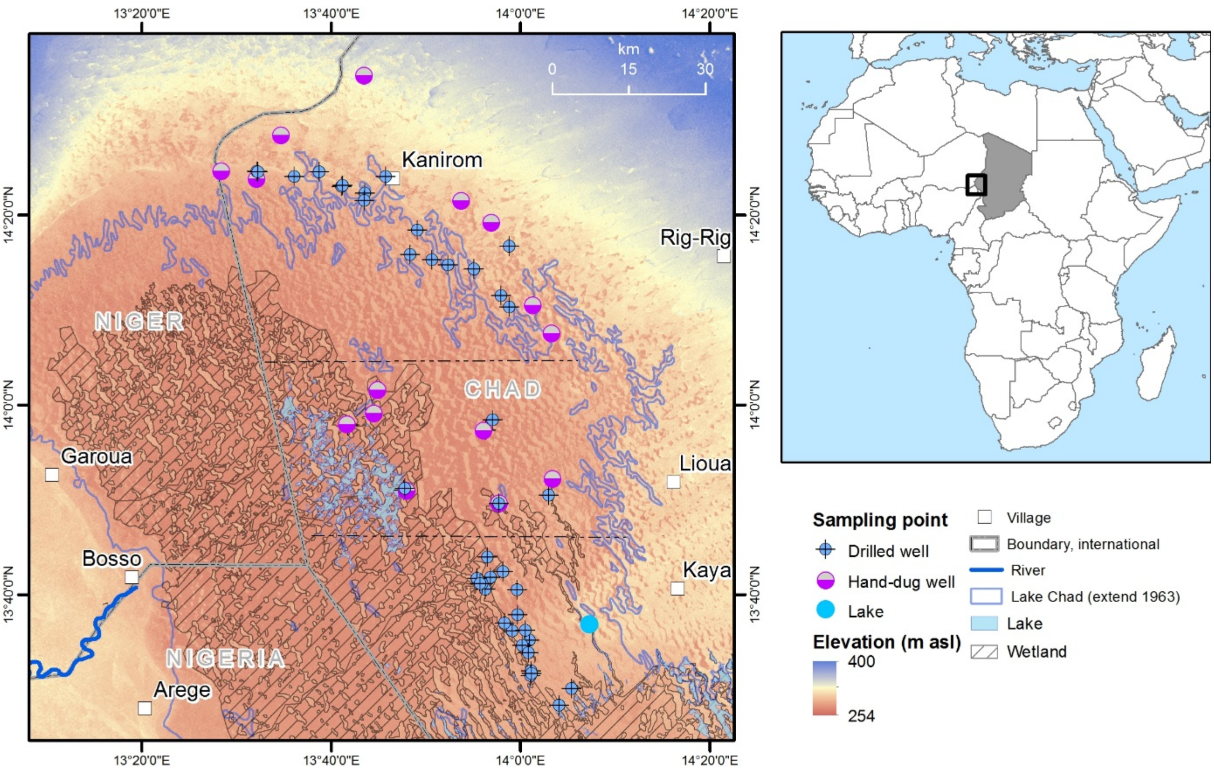

Figure 1: Location of the study area in Africa and the sampling points in the Republic of Chad. The dashed lines indicate the limits between the northern, central and southern sampling sub-areas.

2.2 Climate

The annual precipitation measured at the IAEA station N'Djamena (1964-1978), located approximately 230 km southeast of the study area, varies between 238 mm and 753 mm with an average of 477 mm. For the time period between 1983 and 2013 the average precipitation in N'Djamena is 542 mm with variation between 226 and 775 mm. The rainy season is generally from May to September with maximum precipitation in July and August, but with interannual variations. Precipitation in the region decreases from south to north (Schneider

2001). For the climate station Bol (14.73° East, 13.43° North) average annual precipitation between 1913 and 2008 (data gaps between 1934-1937, 1941-1945, and 1991-1992) is 266 mm.

The average annual minimum temperature in N'Djamena is 21.9 °C and the average annual maximum temperature is 36.1°C for the time period from 1983 to 2013. The interannual variations of minimum and maximum temperatures with standard deviations of 1°C and 0.9°C respectively are rather low.

Measurements at the airport of N'Djamena using a Piche evaporimeter gained an annual potential evaporation of 2686 mm for 2009. Massuel (2001) gives an estimated range of potential evapotranspiration between 2000 and 2500 mm per year for the area.

2.3 Geology, Hydrogeology and Water Abstraction

The Chad basin is a continental sedimentary basin of large thickness. The crystalline basement of Precambrian age is covered by sedimentary deposits of Mesozoic and Cenozoic age (Massuel, 2001). Even though fresh water resources are present in the Cenozoic sediments and in the Pliocene sandstones in particular, the Quaternary deposits of the Chad basin are of uttermost importance in the context of this study, since groundwater for this research was abstracted exclusively from these sequences.

The Quaternary sediments are underlain by clay deposits of Pliocene age (Schneider 2001). The Quaternary sediments north and east of Lake Chad (extend from 1963) are on one hand of eolian and on the other hand of lacustrine origin. The eolian sediments occur in the northern part of the study area and are composed mainly by quartz sand (Ogolian age, Schneider, 2001). Interdunal valleys are either filled with lacustrine deposits which are composed of loamy, clayey and calcareous sediments (e.g. Labdé series) or form saline playas containing sodium carbonate salt (natronières) (Eugster & Maglione, 1979; Servant, 1970). Authigenesis of clay minerals in Lake Chad and neighbouring interdunal systems has been reported as part of the biochemical cycle of silica (Sebag et al., 1999; Carmouze, 1983).The thickness of Quaternary deposits in the study area varies between 60 m in the south and 140 m in the north (Figure 2). Due to the long history and evolution of Lake Chad, stratification of permeable eolian and rather impermeable lacustrine deposits within the Quaternary sediments might be assumed, as clay layers have been documented for some of the available soil profiles in the northern sub-area.

Soil profiles are available only from sampling locations north of Lake Chad (extend from 1963, northern sub-area). According to these profiles, the first 20 to 30 meters below ground surface is mainly composed of fine-grained sand. Clay layers are present only in few places with variable thickness between 2 and 4 meters. It can be assumed that interdunal valleys within the Lake Chad (extend from 1963) of the north depression (central and southern sub-areas) are filled with lacustrine deposits as described for the Kanem region (e.g. Eugster & Maglione, 1974) since interdunal lakes were present during the field campaign in the vicinity of Kaiga Kindjiria, Yakou, Boma, Ngouboua, and Fourkoulom.

The eolian sands form an aquifer of elevated hydraulic conductivity (Schneider, 2001). Massuel (2001) published a value for transmissivity of 0.02 m²/s for a well located at Bol. With a total thickness of quaternary deposits of 89 m, a hydraulic conductivity of $2.25 \cdot 10^{-4}$ m/s is calculated for the Pleistocene sands. For surface depressions (interdunal valleys), Massuel

(2001) gives hydraulic conductivity values between $1 \cdot 10^{-6}$ and $7 \cdot 10^{-5}$ m/s. While the eolian sand aquifer is probably unconfined, confined conditions may occur in the interdunal valleys.

Based on the population census by the NGO Reach in 2016 and an estimated daily water consumption of 15 l per capita and day (regulation of WHO in areas of conflicts, WHO 2013), annual water abstraction in the sous-préfecture Daboua (northern sub-area) sums up to 230.000 m^3 and for Ngouboua (southern sub-area) to approximately 300.000 m^3. Unfortunately no population data could be collected in Kaiga-Kindjira (central sub-area).

3. Methodology

3.1 Spatial Distribution of Sampling Locations

The location of all sampling points with information on the kind of groundwater abstraction is shown in Figure 1. The sampling campaign was done between 07.02.2017 and 14.02.2017 by three different teams. The teams were split into northern, central and southern sampling groups (Figure 1). The northern area is located along the former northern shoreline from Lake Chad (extend from 1963). The central sampling area is in the central eastern area of the north depression and the southern sampling area at the northern rim of the great barrier roughly perpendicular to the barrier extension.

Hand-dug wells are generally located in morphological depressions and drilled wells in the villages on top of dunes. Hand-dug wells in the northern sub-area are flooded more or less each year and are rebuilt periodically. In the central sub-area hand-dug wells are located close to surface water courses and are used all the year.

3.2 Depth of Sampled Groundwater

Drilling and digging depth of all wells sampled during the field campaign are shown in Figure 2. Hand-dug wells are generally shallower than drilled wells, as they are located in morphological depressions. Depth to groundwater is between 2 and 10 meters. For the northern sub-area, the screenings of the drilled wells are mostly just above the well bottom extending between 2 and 6 meters. Hence, sampling depth of collected groundwater may be estimated from drilling depth ranging roughly from 10 to 30 meters.

3.3 Water Analysis

In-situ pH and electrical conductivity of all collected samples were measured using a handheld WTW Multi 3430.

Stable water isotope values $\delta^{18}O$ and $\delta^{2}H$ were analysed at the BGR laboratory using a PICARRO L2120-I cavity ring-down laser spectrometer after vaporisation. Accuracies are better than 0.2 ‰ and 0.8 ‰ respectively. Delta values were measured relative to Vienna Standard Mean Ocean Water (VSMOW).

The analytical methods for water chemistry of the BGR laboratory used in this study are summarized in Table 1.

Table 1: Methods and apparatus used for water analysis.

Parameter	Method	Manufacturer/Type
HCO_3^-, CO_3^{2-}, OH^-	Automatic titrator	SCHOTT Titroline alpha plus
NH_4^+	Photometer	UNICAM UV 300
F^-, Cl^-, NO_2^-, NO_2^-, SO_4^{2-}	Ion chromatography	DIONEX ICS-3000
K^+, Na^+, Mg^{2+}, Ca^{2+}, Br^-, PO_4^{3-}, Fe, Mn	ICP-OES	SPECTRO Ciros CCD
Trace elements	ICP-OES	SPECTRO Ciros CCD

4. Results

4.1 Groundwater Level and Groundwater Flow Direction

The elevation of groundwater level (Figure 2) was calculated from depth to groundwater table measured at the field campaign using a deep-meter and surface elevation from SRTM data (Farr et al., 2000). In order to consider related measurement uncertainties only a subset of the available data were used for data interpolation to gain a very general overview on groundwater elevation and groundwater flow direction. The measured data were interpolated using a thin plate spline technique (Whaba, 1990) developed for the interpolation of elevation surfaces that is implemented in ArcGIS®.

Groundwater flows from northwest (lake extend from 1963) and southeast (great barrier) towards the central part of the study area, where contour lines indicate a local minimum which coincides with the comparably lower elevation of the lake depression. Depth to groundwater table in the north is mainly between 10 and 19 m and in the south between 5 and 10 m.

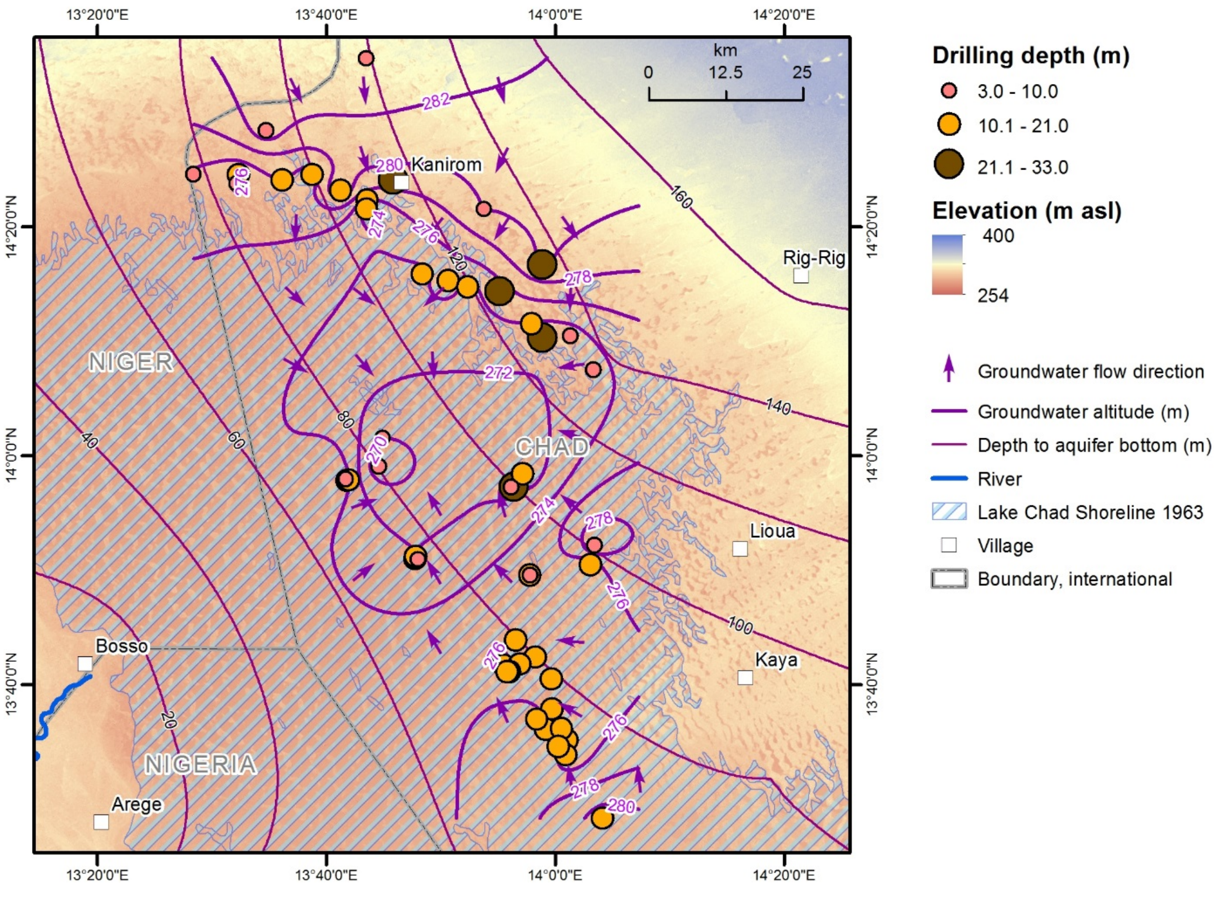

Figure 2: Groundwater contours, direction of groundwater flow, drilling depth of groundwater sampling sites and depth to aquifer bottom. Data for the regionalization of depth to aquifer bottom are taken from Schneider (2001).

4.2 Groundwater Chemistry

4.2.1 Groundwater Classification

The spatial variation of groundwater chemistry within each sub-area is shown in Annex I (Figure 18, Figure 19, and Figure 20). The measured concentrations of all samples and ions/elements are listed in Annex II.

Groundwater in the northern sub-area is invariably classified as Na-HCO_3 water with comparably high amount of total dissolves solids (see Chapter 4.2.2). The groundwater at sampling point Kiskawa urbain[1] contains a comparably high concentration of sulphate. Groundwater at sampling point Belegue 2 has a relatively high concentration of calcium and groundwater at sampling point Soua 1 has relatively high chloride and nitrate concentrations compared to all other sampling points.

Most water samples in the central part of the study area are of Na-HCO_3 type. Exceptions are Yakou III classified as Ca-SO_4 groundwater as well as two of the groundwater samples collected in Boma (LAC-Eq_2-AQ-08, LAC-Eq_2-AQ-10) and the sample Digou I that are of Na-SO_4 type. Yakou and the third sample collected in Boma (LAC-Eq_2-AQ-09) with the lowest amount of total dissolved solids (TDS[2]) among the three Boma samples are Ca-HCO_3 groundwater. In general, the groundwater of the central part of the sampling area is characterized by variable mineralisation compared to the groundwater of the northern sub-area (see chapter 4.2.2).

Most of the groundwater samples collected in the southern sub-area are Na-HCO_3 groundwater. The samples collected at Kousserie (LAC-Eq_1-AQ-04) and at Hakoye Ndilliah are Na-SO_4 groundwater. The sample from Loliya is Na-Ca-Mg-SO_4 water. Groundwater at sampling point Kaya is typified as Ca-Na-SO_4. The lowest mineralised groundwater from the three samples collected at Ngouboua (LAC-Eq_1-AQ-17) and the groundwater sample at sampling location Boudoumoram are Ca-HCO_3 groundwater.

The lake water collected at Fourkoulom is Ca-Na-K-HCO_3 water with a comparably low mineralisation.

Groundwater chemistry from this study area differ from those evaluated for the regions Kanem and Bahr el Ghazal (Vassolo 2014). However, similarities between this study and Bahr el Ghazal are obvious since dominant anions and cations are similar. The potential recharge water of Lake Chad from this study differs slightly to those of Vassolo (2014). Recharge water in Vassolo (2014) was classified as calcium magnesium bicarbonate type, lake water at Fourkoulom is of the calcium sodium potassium magnesium bicarbonate type. Chemical variations of recharge waters may be explained by the specific geochemical and biogeochemical processes within the Lake Chad and interdunal systems with related precipitation of iron, aluminium, calcium and magnesium compounds which results in elevated concentrations of sodium and potassium (Carmouze, 1983).

[1] Location see Figure **18** - Figure **20**
[2] Total dissolved solids (TDS) are calculated from the chemical analyses.

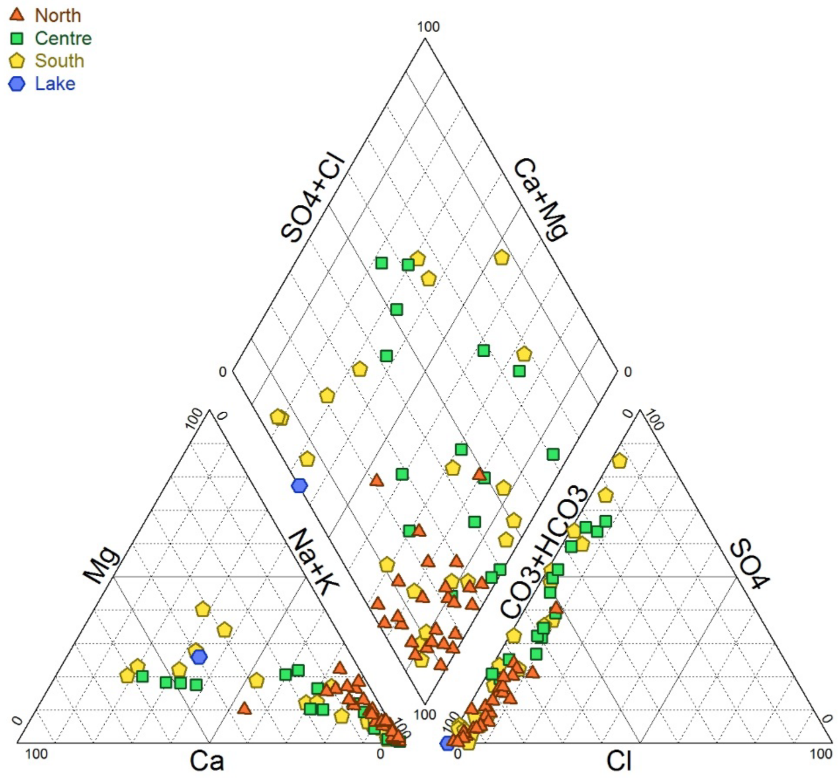

Figure 3: Piper Plot of all collected water samples.

In summary groundwater chemistry has sodium-bicarbonate dominance. However, in the sub-areas located within the Lake Chad extend from 1963, groundwater chemistry is more variable than along the former northern shoreline. In these sub-areas groundwater has sulphate dominance in places.

4.2.2 Salinity

The content of TDS of the groundwater is generally higher in the northern part of the study area and decreases in southern direction. Average TDS is 3604 mg/l in the north, 2656 mg/l in the centre and 1850 mg/l in the south of the study area. The lake water has a very low amount of TDS: 130 mg/l.

The spatial variability of TDS is lower in the northern, but higher in the central and southern parts of the study area. TDS in the southern area correlates neither with drilling depth nor with depth to groundwater table. In the central part of the study area, TDS varies with the type of water extraction system. The traditional hand-dug wells show significantly lower TDS values than the drilled wells (two-site student-t test). The depth to groundwater table as well as the drilling depth for the hand-dug wells are generally lower than for the drilled wells in this area.

In the northern part hand-dug wells are shallower too, but TDS values are not necessarily lower than those for drilled wells. All sampling points in the southern area belong to drilled wells because hand-dug wells were not sampled there. However, strong spatial variabilities of TDS values were measured.

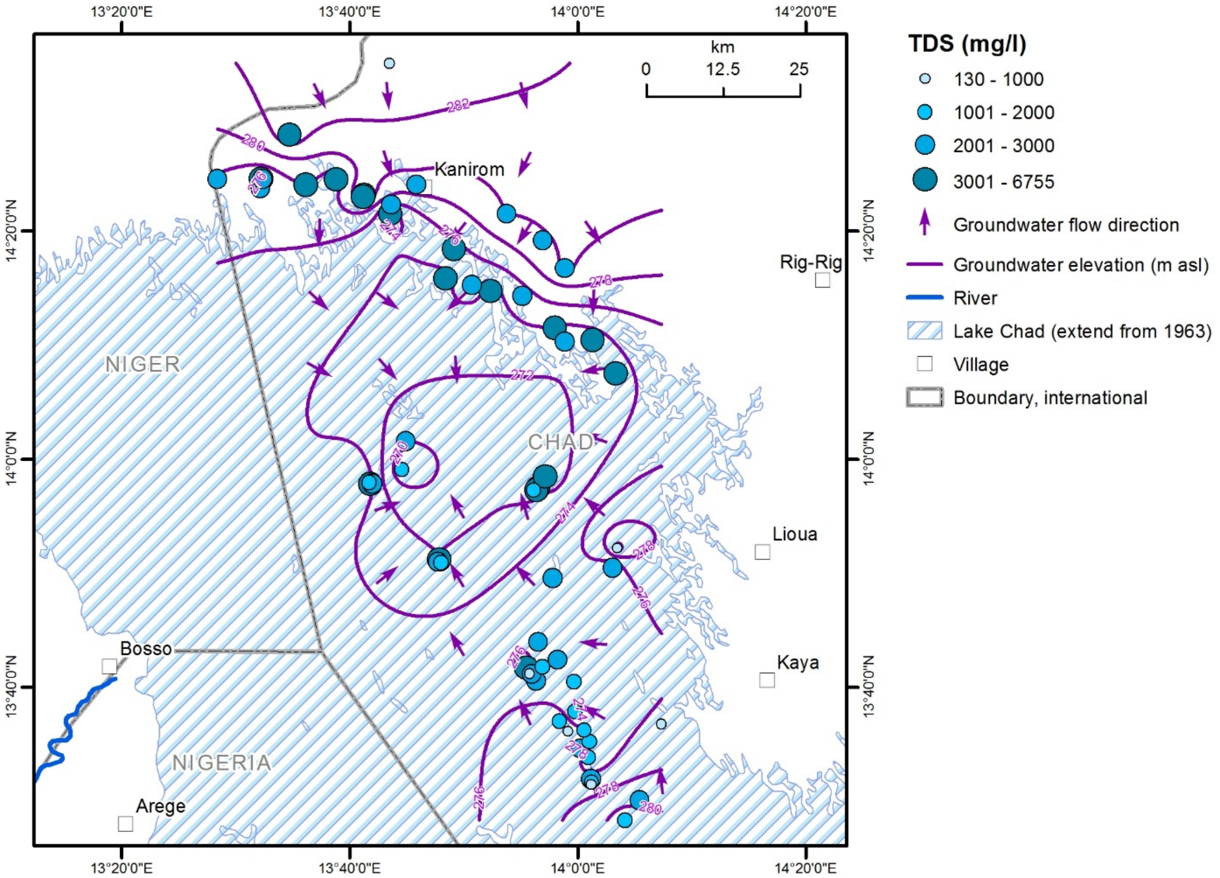

Figure 4: Total dissolves solids (TDS) of all collected samples, groundwater elevation and flow direction.

4.2.3 Stable Isotopes – Deuterium and Oxygen-18

The stable isotopes deuterium and oxigen-18 are measured for all collected water samples and compared to values from precipitation (IAEA network) and historical data from other studies (UNESCO, 1970).

The local meteoric water line N'Djamena differs from the global meteoric line indicating isotope fractionation due to evaporation (Figure 5). For the local water line, the relation between both isotopes can be described by the following equation:

$$\delta^2H = 6.83\ \delta^{18}O + 5.592$$

The average weighted isotopic composition of the precipitation in N'Djamena between 1964 and 1995 (with certain data gaps) is $\delta^2H = -0.22$ and $\delta^{18}O = -0.04$.

The isotopic composition of the collected groundwater spread along a linear trend following the equation

$$\delta^2H = 5.67\ \delta^{18}O + 6.064$$

The surface water sample from Lake Chad collected in the vicinity of Fourkoulom plots closely to the samples of the southern sub-area. Surface water from studies dated from February 1967 plots along a linear trend indicating even stronger evaporation (lower gradient) compared to the recent water samples:

$$\delta^2H = 4.48\ \delta^{18}O + 3.253$$

The isotopic composition of the collected groundwater samples varies for the sub-areas. The range of composition for the samples of the northern sub-area is much larger than for the other sub-areas. The lowest range is measured for the southern sub-area. This observation may be interpreted as due to different infiltration and percolation behaviours. In the northern sub-area infiltration and percolation through the permeable eolian sand deposits occurs relatively fast and consequently the interannual isotope signal of precipitation water is transferred quickly and only with a minor signal damping towards the groundwater. Recharge processes in the other sub-areas differ from those of the Ogolian deposits because of the low permeable deposits within the interdunal valleys that retard water percolation. Reduced flow velocity in the vadose zone results in higher transit times and mixing of infiltrating water with different isotopic compositions results in a more effective dumping of the isotopic signal within shorter distances.

Another aspect concerning the variation of isotopic composition might be the source of recharge. In the north, all recharge is generated by precipitation. In the central and southern sub-area a significant part of the recharge might be generated by bank infiltration. Infiltrating surface water has a differing isotopic composition compared to precipitation. However, the temporal evolution of its composition during the last years is not known and infiltration condition might vary locally.

In consequence, solute transport from the surface to the groundwater table is faster in the northern sub-area with transit time in the range of several month to less than two years, depending on the local and particular climate conditions. Higher residence times in the vadose zone of several years in the central and the southern sub-area might be anticipated. The significance of recharge water bypassing the vadose zone via bank infiltration cannot be estimated.

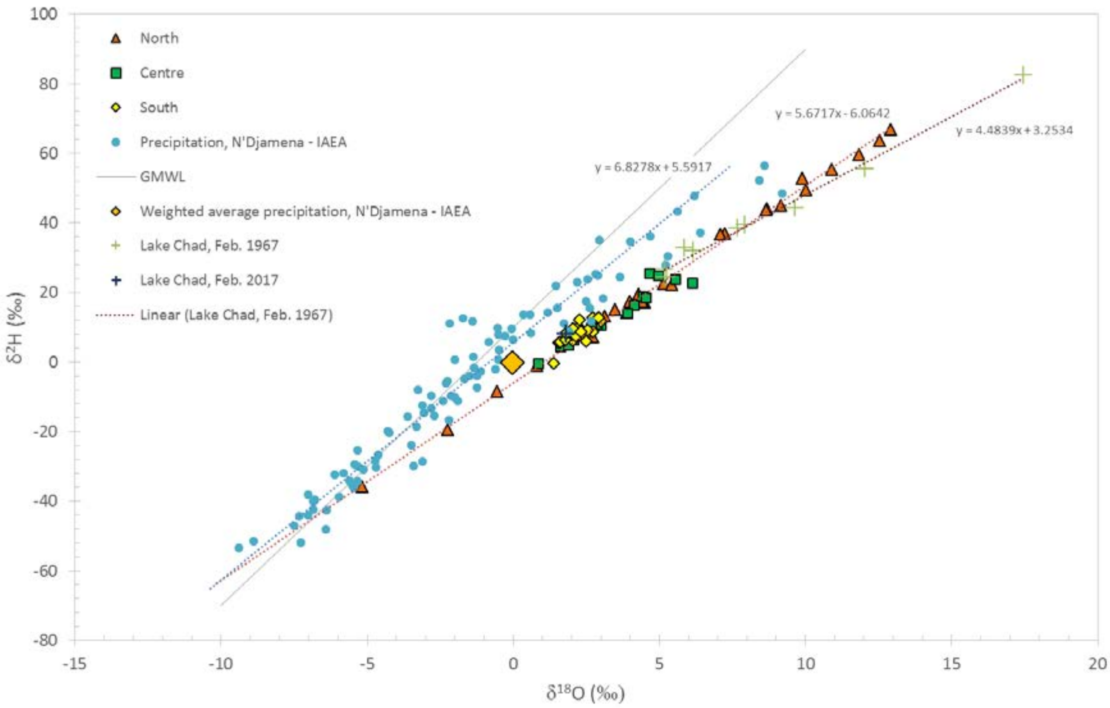

Figure 5: $\delta^{18}O$ vs. $\delta^{2}H$ for all collected samples as well as historical data from precipitation collected in February 1967 at the DREM station in N'Djamena and surface water from Lake Chad (data source: UNESCO, 1970). The dashed blue line is the local meteoric water line for N'Djamena, the dashed black line is the linear trend calculated for all collected groundwater samples and Lake water from Feb. 1967. GMWL: Global meteoric water line.

4.3 Groundwater Quality

4.3.4 Groundwater Chemistry and WHO-Guideline

Long-term exposure to **arsenic** in drinking-water is causally related to increased risk of cancer as well as dermal lesions and other skin changes (WHO, 2011). The guideline value is designated as 0.01 mg/l. The water samples have been measured using inductively coupled plasma optical emission (ICP-OE) (Table 1) with a detection limit of 0.02 mg/l, which is higher than the WHO guideline value of 0.01 mg/l. Therefore, groundwater samples exceeding this detection limit are discussed in detail.

Only eight of the analysed groundwater samples have concentration of arsenic above the detection limit of ICP-OES (Figure 6): three samples in the northern, three samples in the central and two samples in the southern sub-area. The highest arsenic concentration was measured in Soua 1 with 0.19 mg/l (northern sub-area) and Boma with 0.1 mg/l (LAC-Eq_2-AQ-10, central sub-area). The lowest detected arsenic concentrations were measured in the sample of Kousserie (0.02 mg/l at LAC-Eq_1-AQ-04 and 0.04 mg/l at LAC-Eq_1-AQ-06) located within the southern sub-area. There is no correlation between arsenic and any other parameter that has been measured or analysed during the sampling campaign.

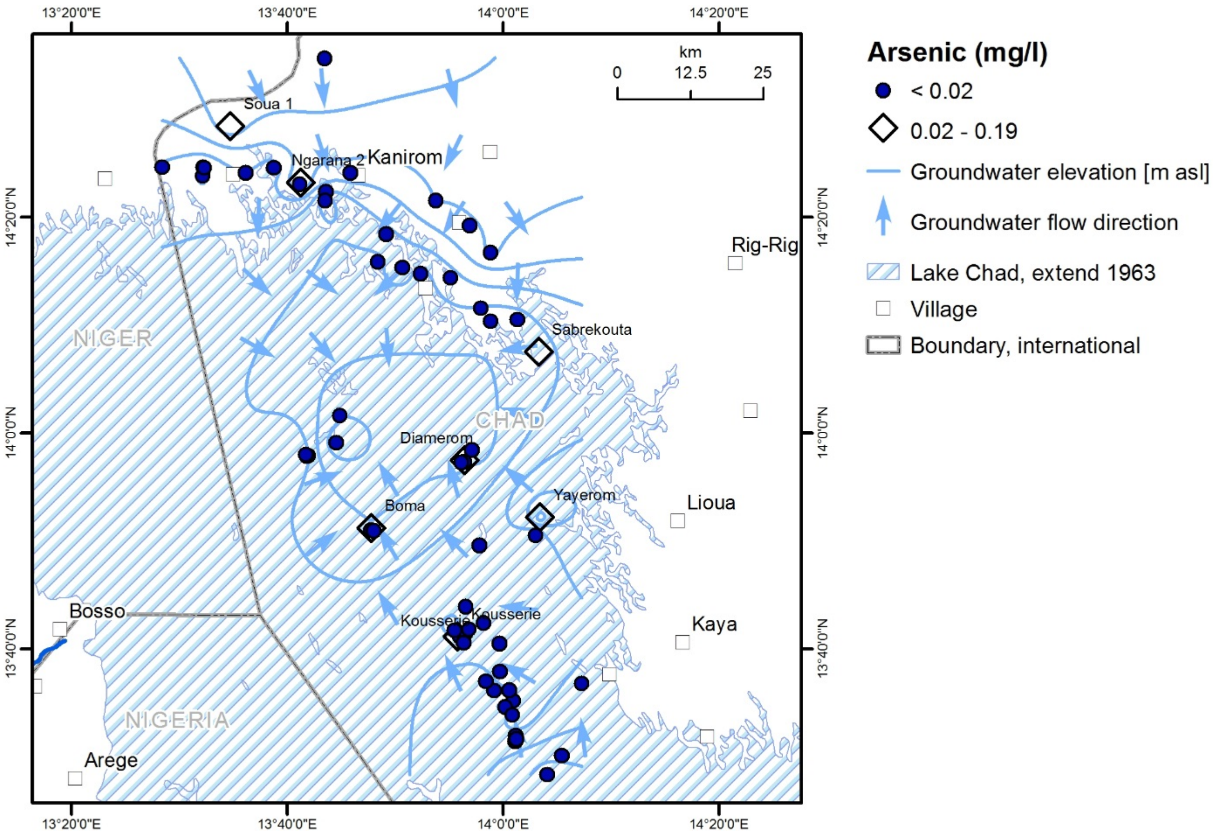

Figure 6: Spatial distribution of arsenic in the study area. Open diamonds indicate locations where arsenic concentration exceeds the ICP-OES detection limit as well as the WHO guideline value.

Barium appears to be potential to cause hypertension. The guideline value is 0.7 mg/l. Only the groundwater samples located at the southernmost sampling location exceeds this value: Kangalia with 0.95 mg/l.

The guideline value for **boron** (BO_2) is 2.4 mg/l. Three samples in the northern sub-area exceed this value: Aligua Koulboua with 2.5 mg/l, Chebrey F3 with 2.76 mg/l, and Borora F4 with 2.98 mg/l (Figure 7). In general Boron concentration is slightly correlated with HCO_3-concentration (correlation coefficient = 0.875).

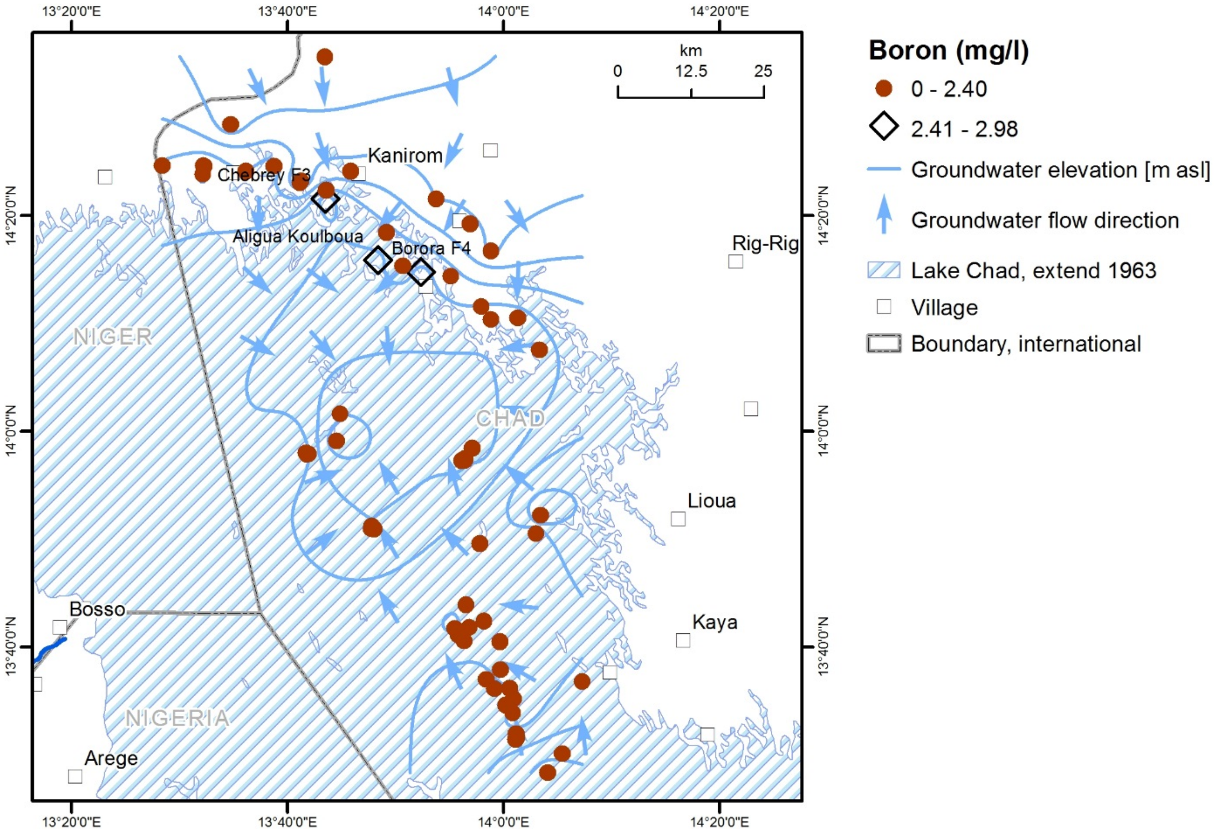

Figure 7: Spatial distribution of boron in the study area. Open diamonds indicate locations where boron concentration exceeds WHO the guideline value.

Epidemiological studies of possible adverse effects of the long-term ingestion of **fluoride** via drinking-water clearly establish that high fluoride intakes primarily produce effects on skeletal tissues. Fluoride can have an adverse effect on tooth enamel. The WHO guideline value is defined at 1.5 mg/l.

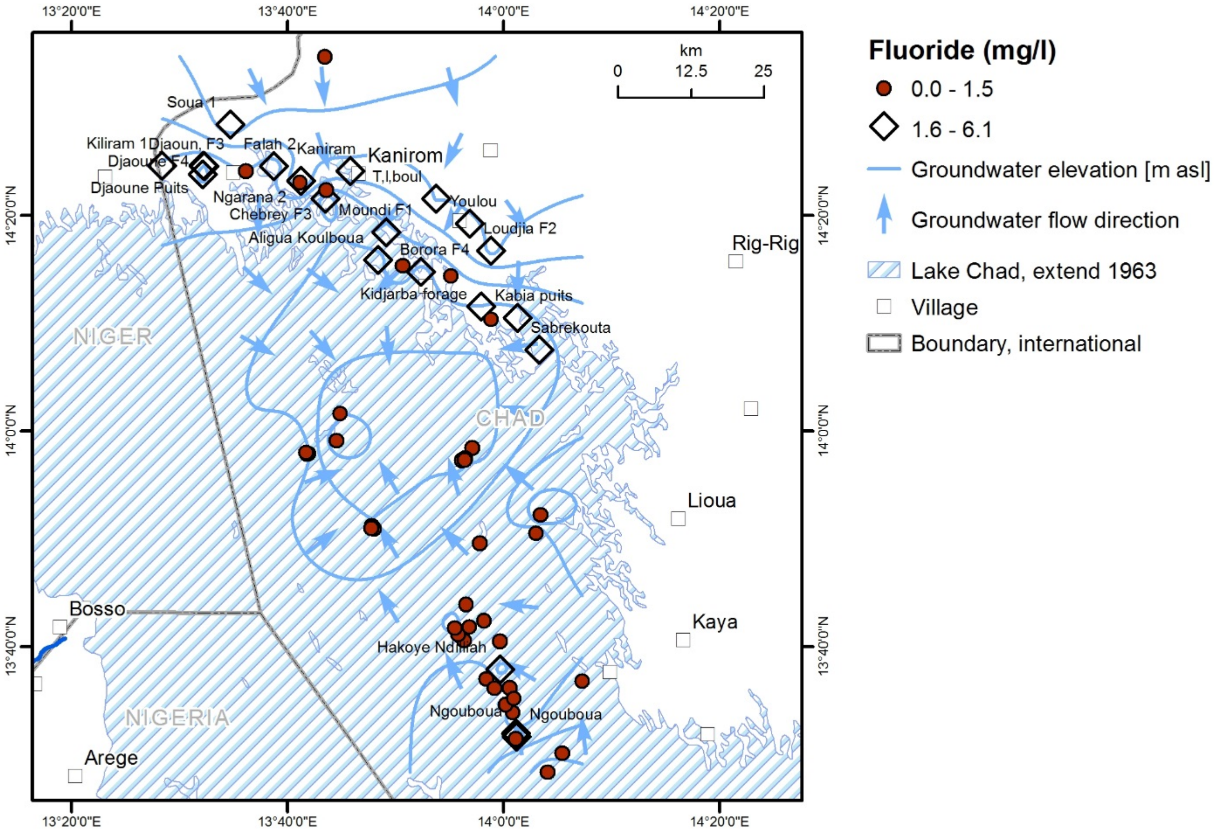

Figure 8: Spatial distribution of fluoride in the study area. Open diamonds indicate locations where fluoride concentration exceeds the WHO guideline value.

In 21 groundwater samples fluoride concentration exceeds the WHO guideline value (Figure 8). Most of these samples are located in the northern sub-area. Only three of these groundwater samples are within the southern sub-area. None of the groundwater sampling points within the central sub-area have values higher than the guideline value. The highest value of 6.06 mg/l fluoride was measured in Soua 1. But also at other groundwater sampling locations in the northern sub-area relatively high fluoride concentration were measured, e.g. Chebrey F3, Kaniram, Sabrekouta and Borora F 4. Fluoride concentration above the guideline value in the southern sub-area are below 2.5 mg/l.

Nitrate is naturally found in the environment and is an important plant nutrient. Nitrate can be present in groundwater, due to leaching from natural sources or due to anthropogenic impact, e.g. agricultural activities, i.e. especially animals close to water point, wastewater disposal, leaching of latrines, or uncontrolled and open defecation. Nitrate concentration in groundwater below forests does normally not exceed 10 mg/l (DVWK, 1996). The guideline value for nitrate is 50 mg/l to protect against methaemoglobinaemia in bottle-fed infants (WHO, 2011).

In total 14 groundwater samples have nitrate concentration that exceeds 10 mg/l and eleven samples have a nitrate concentration of more than 50 mg/l. In general nitrate concentrations above the guideline value are more frequently in the central and southern part of the study area. Groundwater at sampling point Soua 1 has 352 mg/l nitrate and is the only sample that exceeds the WHO guideline value of 50 mg/l in the northern sub-area. Even higher concentrations were measured at Boma (LAC-Eq$_2$-AQ-10) with 440 mg/l and at Digou I with 568 mg/l nitrate, both sampling points located in the central part of the study area. Other sampling location exceeding nitrate concentrations of 100 mg/l are Ngouboua (150 mg/l), Kaya

(155 mg/l) and Hakoye Ndilliah (345 mg/l) all of them located in the southern part of the study area.

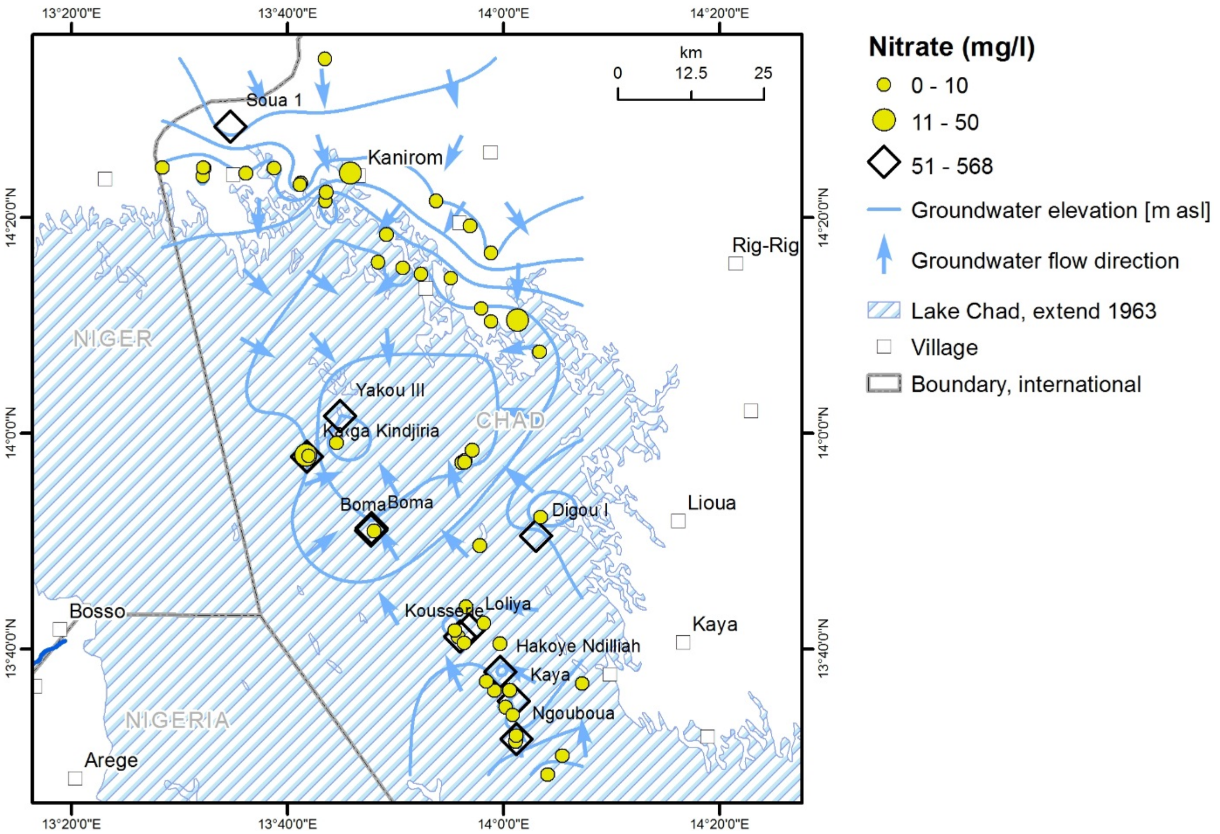

Figure 9: Spatial distribution of nitrate in the study area. Open diamonds indicate locations where nitrate concentration exceeds the WHO guideline value. Elevated nitrate concentrations, but still below the WHO limit are indicated by the large filled circles.

Methaemoglobinaemia is a consequence from reaction of **nitrite** with haemoglobin that results in blocking of oxygen transport and can cause cyanosis, the blue-baby syndrome (WHO, 2011). The guideline value for nitrite is 3 mg/l. The combined guideline value for nitrate and nitrite is the sum of ratios of the measured concentrations to its guideline value and should not exceed 1.

Five groundwater samples exceed the guideline value for nitrite, most of them located in the northern sub-area (Figure 10). The highest nitrite concentrations were measured at sampling locations Borora F4 with 19.6 mg/l and Kabia puits with 10.7 mg/l. Only at one sampling point in the southern sub-area, Hakoye Ndilliah with 8.49 mg/l, the nitrite concentration exceeds the guideline value.

At two sampling locations the sum of nitrate and nitrite ratios exceeds the guideline value, while meeting the requirements for nitrate and nitrite at the same time. These two sampling points are Kaniram and Djaoun F3 both located in the northern sub-area.

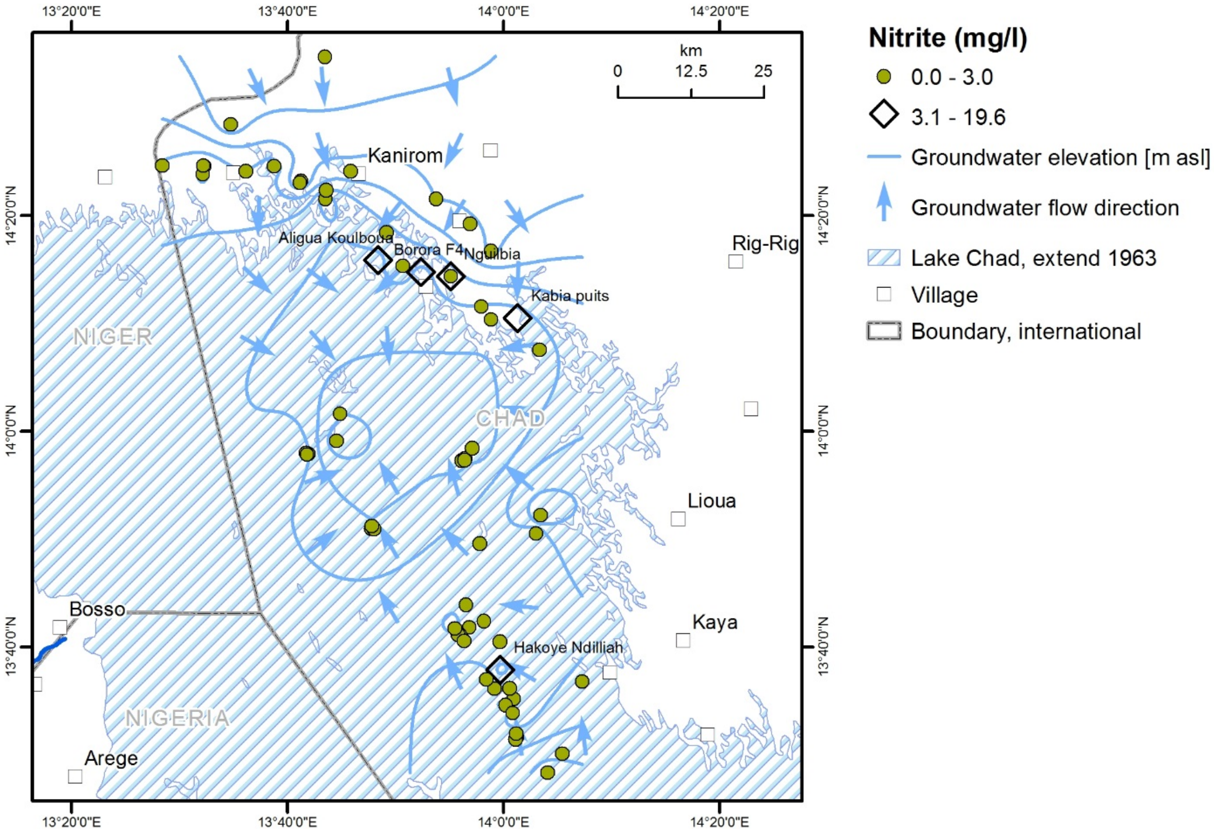

Figure 10: Spatial distribution of nitrite concentration in the study area. Open diamonds indicate locations where nitrite concentration exceeds the WHO guideline value.

4.3.5 Other Indicators of Groundwater Quality

Except from the WHO guideline values, other indicators for groundwater quality may help to classify water for drinking purposes and to give indications for future improvements. Empirical values may help in this context to assist in ranking the groundwater samples with respect to drinking-water quality. The following parameters were found to be critical with respect to empirical values for drinking-water purposes: ammonia, aluminium, manganese, sodium, iron, and sulphate.

High concentrations of **ammonia** may give rise to limitations in drinking-water quality. Ammonia concentrations above 1.5 mg/l may result in olfactory limitations and concentrations above 35 mg/l may cause taste problems. Ammonia in water is an indicator for anthropogenic impact, due to sewage and animal waste pollution (WHO, 2011).

Ammonia concentrations above 1.5 mg/l were measured mainly in the northern part of the study area (Figure 11). One sample in the central and four samples in the southern sub-area are above the 1.5 mg/l olfactory value. Exceptional high concentrations were measured at Kabia puits (northern sub-area) with 135 mg/l and Koloa Gagnant (southern sub-area) with 41.6 mg/l ammonia.

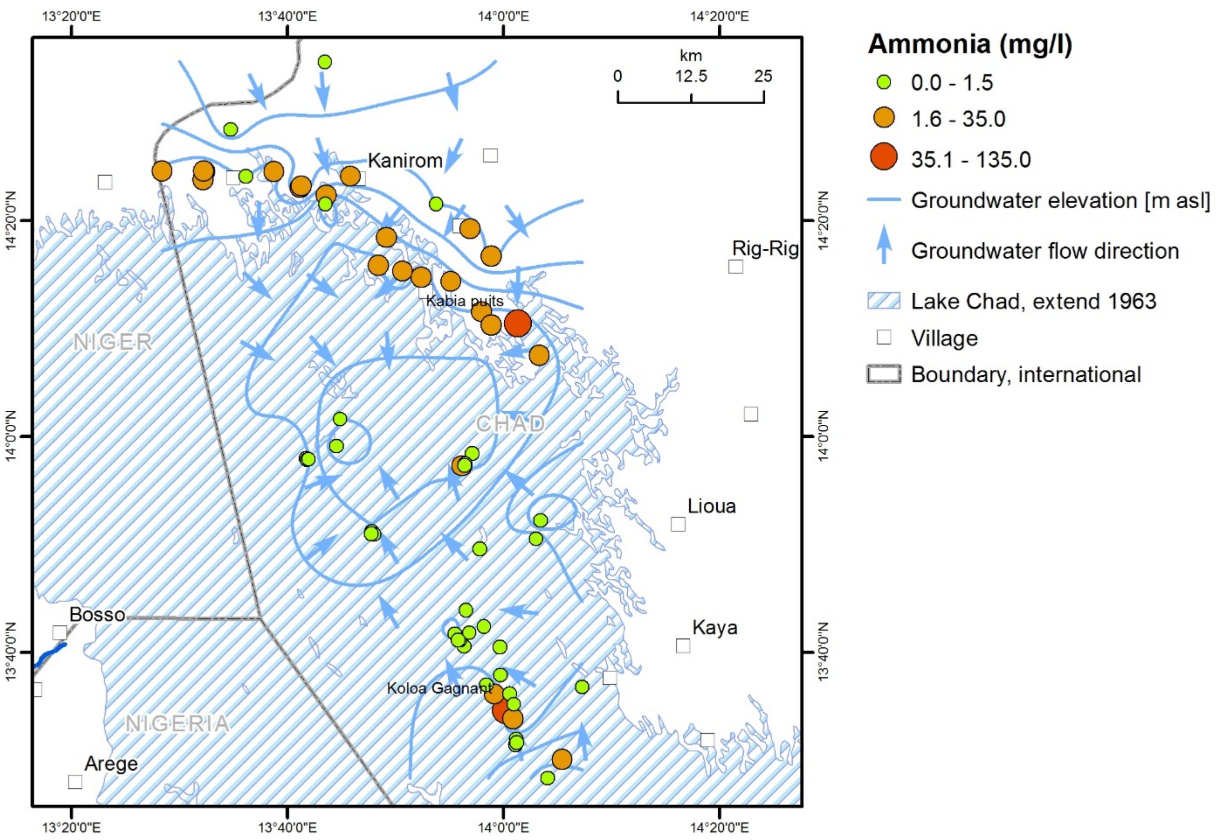

Figure 11: Spatial distribution of ammonia concentration in the study area.

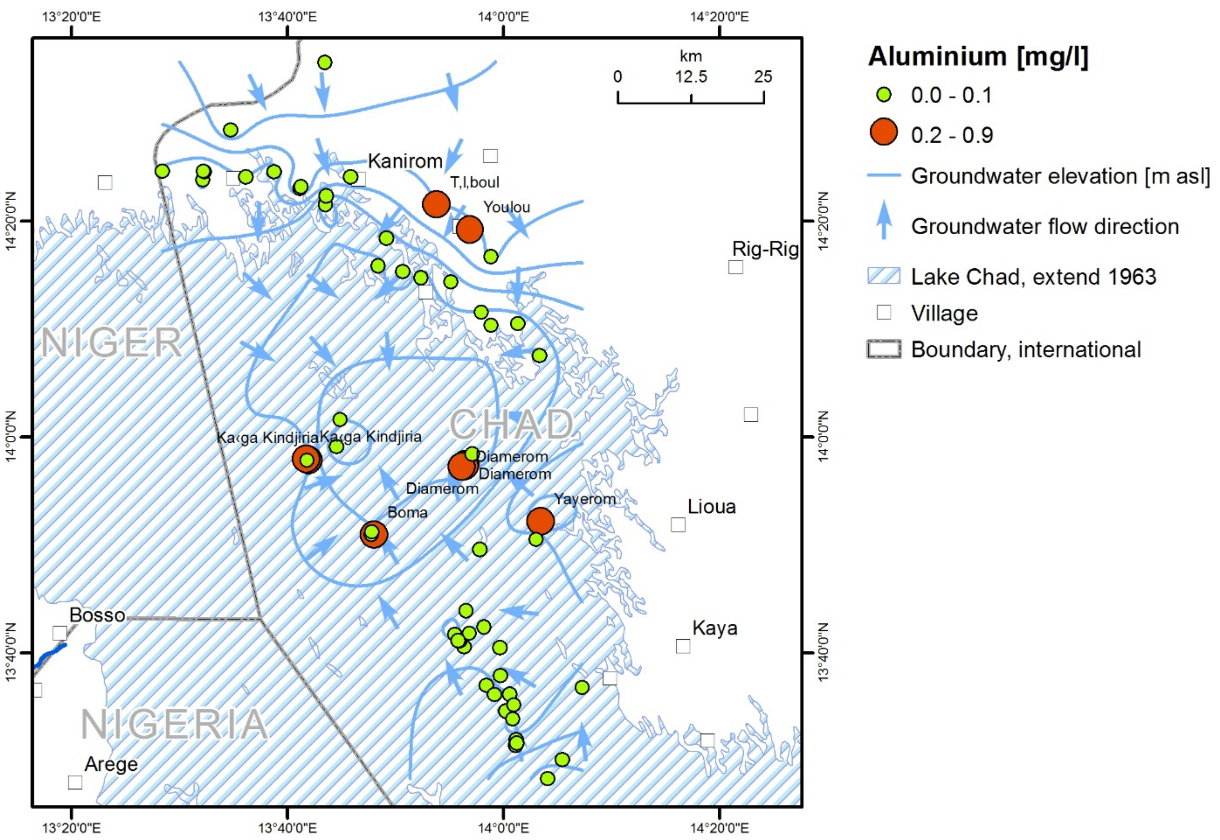

Figure 12: Spatial distribution of aluminum concentration in the study area.

WHO (2011) does not propose a health-based guideline value for **aluminium** in drinking-water. However, high concentration may lead to undesired colour and turbidity. Furthermore, a health-based value at 0.9 mg/l may be derived from related studies. For practical purposes based on coagulation processes in drinking-water plants where aluminium is frequently used, it is important to ensure that a concentration of 0.1 mg/l aluminium in drinking-water is not exceeded (WHO, 2011).

Aluminium concentration does not exceed the critical concentration of 0.9 mg/l in the water samples collected in the study area. Only at a few sampling points in the northern and central sub-areas aluminium concentration is between 0.1 and 0.9 mg/l (Figure 12).

A health-based value of 0.4 mg/l can be derived for **manganese**. This health-based value is estimated by WHO (2011) to be well above concentrations normally found in groundwater. Therefore, it is not considered necessary to derive a guideline value (WHO, 2011). Manganese concentrations above 0.1 mg/l may cause an undesired taste and could lead to the accumulation of deposits in distribution systems.

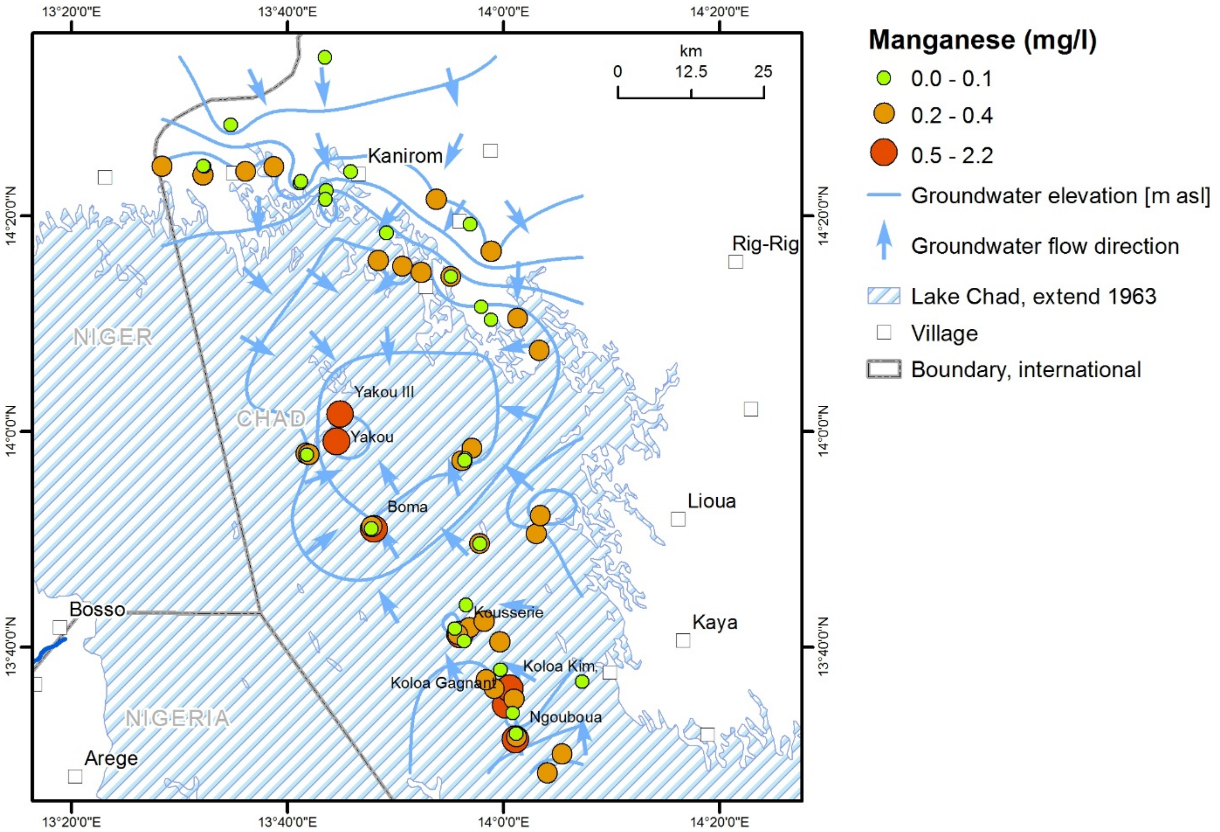

Figure 13: Spatial distribution of manganese concentration in the study area. Sampling locations with manganese concentrations above 0.4 mg/l are labeled with the location names.

In total 30 samples have manganese concentrations above 0.1 mg/l and below 0.4 mg/l: twelve sampling locations on the northern sub-area, eight in the central part of the study area, and ten in the southern sub-area. Seven samples out of all collected water samples are above this health-based value, all of them located in the central and southern sub-areas (Figure 13). The highest concentration was measured in groundwater collected in Ngouboua with 2.17 mg/l. Concentrations above 1 mg/l were measured in groundwater from sampling locations Yakou and in one of the samples collected in Boma (LAC-Eq2-AQ-09). Concentrations above 0.5 mg/l were measured in samples from Koloa Gagnat, in one of the samples collected in Kousserie (LAC-Eq1-AQ-04), and in Yakou III. At Koloa Kim manganese concentrations in groundwater are just below 0.5 mg/l.

The taste threshold for **sodium** is 200 mg/l at room temperature but no health-based value has been derived (WHO, 2011), as no firm conclusion concerning possible association of sodium in drinking-water and hypertension can be drawn.

In total 48 samples exceed the threshold sodium concentration of 200 mg/l. Almost all samples collected in the northern sub-area have more than 200 mg/l sodium (Figure 14), except for sample Belegue 2. Sodium is the major cation in most of the samples and highly correlated to the electrical conductivity (EC). Hence, sodium concentration can be approximated by EC-measurement using the linear relationship

$$C_{Na\ (mg/l)} = 0.26042 \cdot EC_{\mu Scm^{-1}} + 198.33$$

with $R^2 = 0.95$

Since EC values are highly correlated to TDS, sodium concentration is positively correlated to TDS values too.

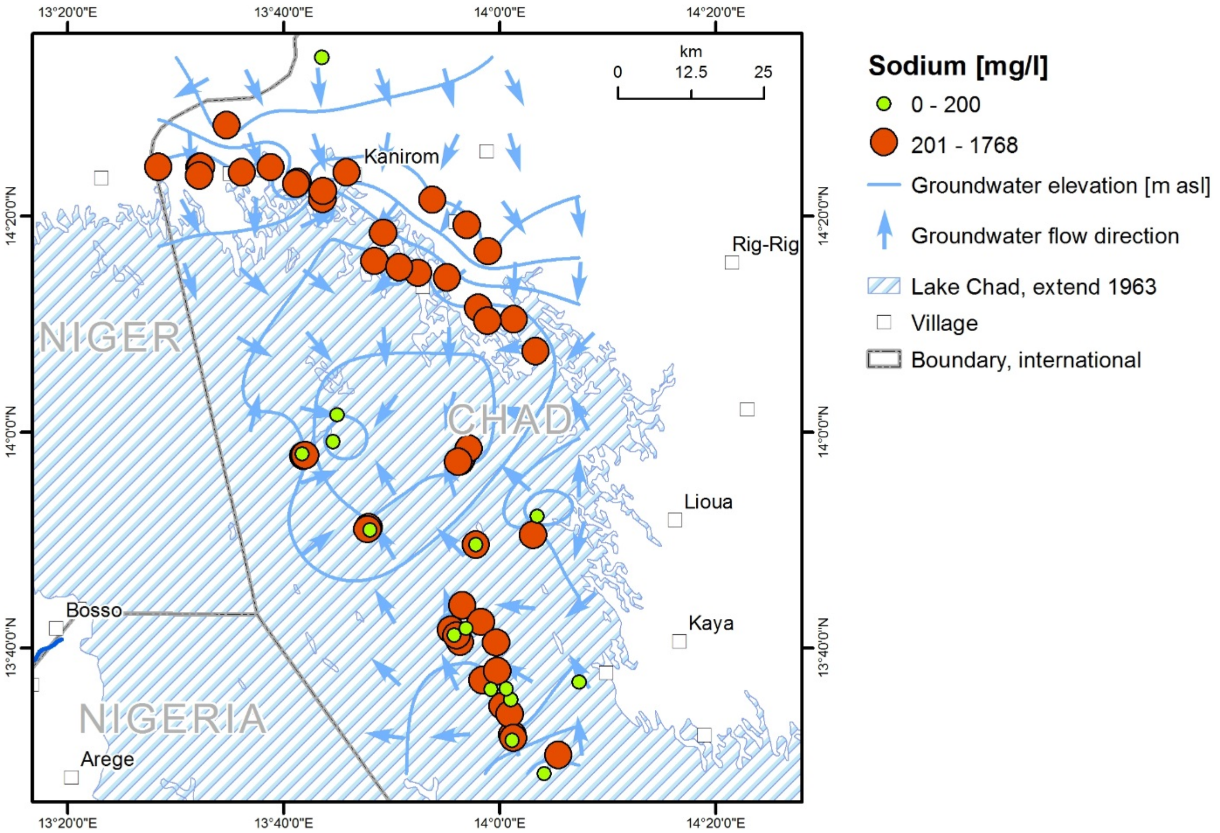

Figure 14: Spatial distribution of sodium concentration with indication of possible taste problems.

Anaerobic groundwater may contain ferrous **iron** up to several milligrams per litre, which is oxidized to ferric iron on exposure with the atmosphere giving a reddish-brown colour to the water (WHO, 2011). Below iron concentrations of 0.3 mg/l there is usually no noticeable taste and at levels above 0.3 mg/l iron stains laundry and plumbing fixtures. The Provisional Maximum Tolerable Daily Intake (PMTDI) of iron in drinking-water is about 2 mg/l. As taste and appearance of drinking-water is affected below this value, no guideline value was proposed (WHO, 2011).

Iron concentrations above 0.3 mg/l were measured for 18 samples, five samples in the northern, six samples in the central and seven samples in the southern sub-area (Figure 15). The maximum value of 2.25 mg/l was measured in the sample Koloa Gagnant located in the southern sub-area.

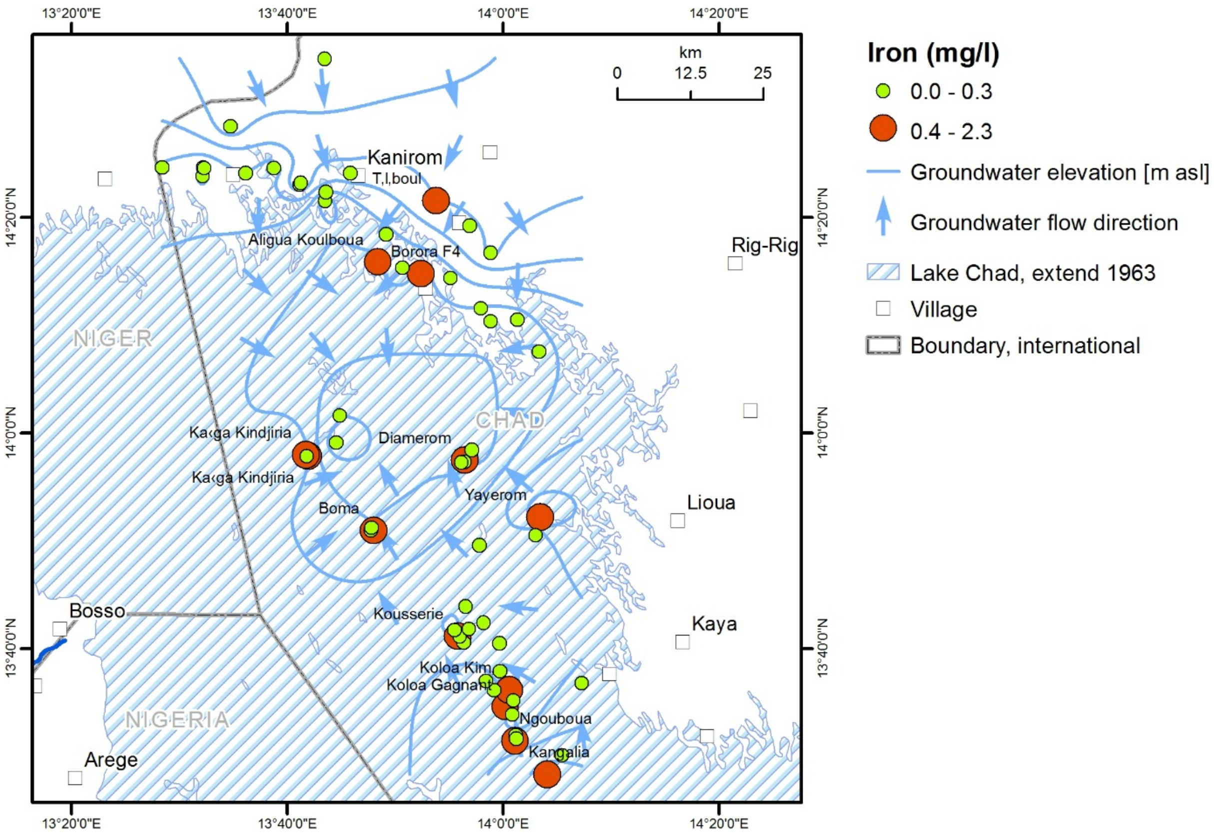

Figure 15: Spatial distribution of iron concentration in the study area.

Taste threshold for sodium sulphate is 250 mg/l. According to WHO (2011) **sulphate** is not of health concern at levels found in drinking-water. Accordingly, no guideline value was proposed. However a laxative effect at concentrations of 1000 – 1200 mg/l was indicated by studies with human volunteers. It is recommended that health authorities are notified of sources that contain sulphate in excess of 500 mg/l.

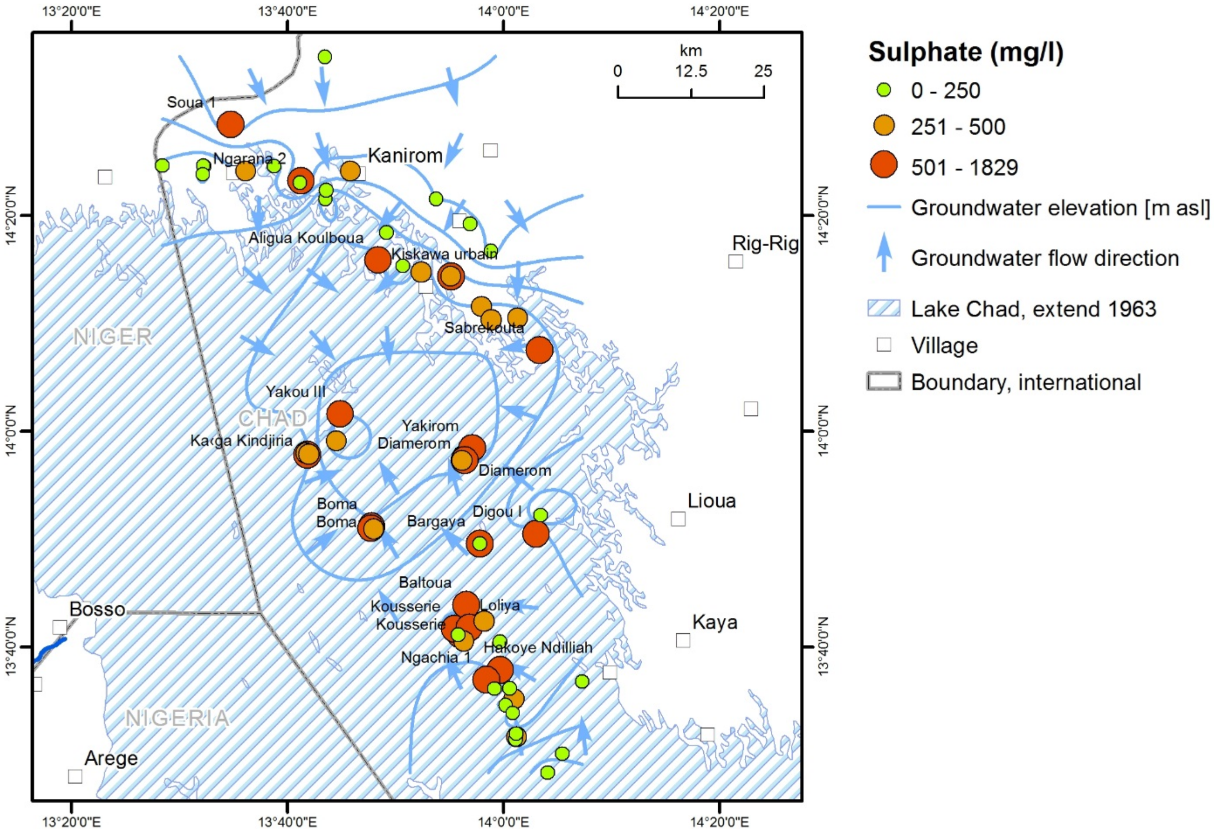

Figure 16: Spatial distribution of sulphate concentration in the study area.

In the study area, 36 samples contain more than 250 mg/l and 20 samples more than 500 mg/l sulphate (Figure 16). The highest concentration of 1829 mg/l was measured in one of the samples collected in Boma (LAC-Eq_2-AQ-10). Although sulphate may origin from industrial sources and be discharged into water through waste and atmospheric deposition, highest levels in groundwater are usually from natural sources, e.g. caused by dissolution of minerals.

5. Conclusions and Recommendations

The majority of the sampled groundwater is not suitable for drinking-water purposes as 38 out of 63 water samples (60%) have a chemical composition that does not meet the WHO recommendation concerning drinking-water quality (Figure 17). Considering the other limitations for drinking-water quality discussed in chapter 4.3.5, only five samples are suitable for drinking-water purposes:

- Belegue 2 in the northern sub-area,
- Kaiga Kindjiria (LAC-Eq2-AQ-04) in the central sub-area,
- Boudoumoram and Kangalia in the southern sub-area and
- Surface water from the sampling point Fourkoulom.

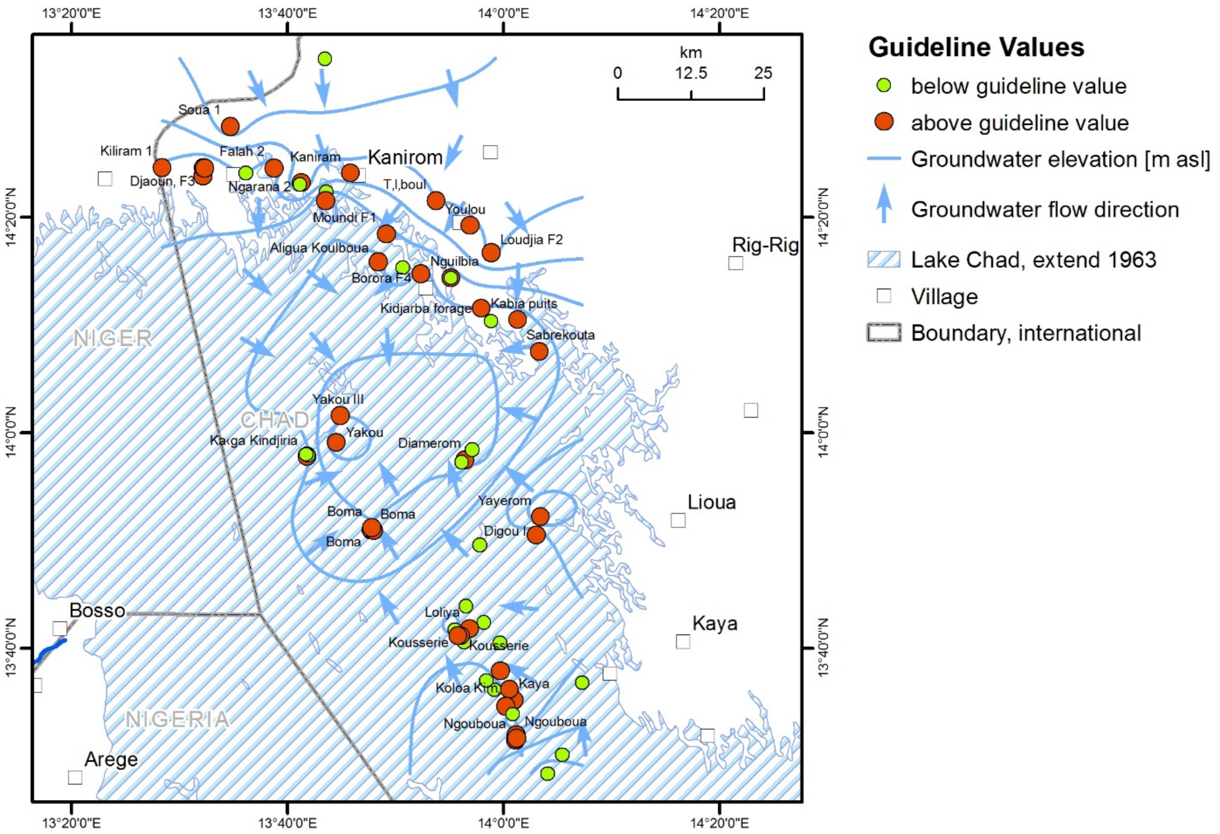

Figure 17: Classification of water samples according their chemical composition with respect to WHO guideline values for drinking-water.

Fluoride concentration is the major limitation of water quality according WHO (2011) in the northern sub-area. Concerning limitations in taste, sodium concentration is the responsible ion, which exceeds in more than 75 % of all sample the threshold value of 200 mg/l. Almost all samples in the northern sub-area and most of the samples in the central and southern sub-area are affected.

Indicators for anthropogenic impact on groundwater quality are nitrate, nitrite and particularly ammonia. Elevated concentration of ammonia are measured mainly in the northern sub-area, but nitrate concentrations above the guideline value occurs in some places of the central and southern sub-area too. The vulnerability of the groundwater resource to contamination is in the northern sub-area generally higher, due to the comparably high permeable eolian sand deposits whereas interdunal deposits may have comparably higher protective properties. Local groundwater flow in the central part of the study area, e.g. via bank filtration from fresh surface water to the hand-dug wells, seems to have a positive effect on groundwater quality in term of lower amounts of dissolved solids.

The source of sulphate encountered in groundwater of some wells are not readily identifiable. Potential sources might be evaporitic sediments in the vadose zone or plant tissue at the surface, which are dissolved during ponding, infiltration, and percolation. Further investigations are necessary to find the sulphate source and thus be able to identify related groundwater management options.

Improved protection of groundwater implementing appropriate measures may solve only some of the groundwater quality aspects of the study area. Problems associated with the dissolution of specific ions in water during infiltration, percolation, and groundwater flow may not be solved using the common tools of drinking-water protection. To overcome these problems identification of other sources of drinking-water might be appropriate. In this context exploration of deeper groundwater should be considered. We like to emphasize that groundwater used for water supply is extracted from rather shallow depths compared to the total thickness of the aquifer. The permeable Quaternary deposits are much thicker than the drilling depth from recent wells and groundwater from deeper positions may contain less dissolved solids as proposed by Arad & Kafri (1975). This might be the case in particular at such locations, where the aquifer has a certain stratification that separates the groundwater resources vertically. Consequently, we recommend to investigate the deeper parts of the Quaternary aquifer for its suitability as drinking-water resource depending on the spatial location.

Another alternative drinking-water resource might be the permeable deposits of the lower Pliocene and Miocene (Continental Terminal). The groundwater of the lower Pliocene has usually a rather high mineralization, but the Continental Terminal is low mineralized although it has probably a comparably low thickness within the study area (Schneider & Wolff, 1992). However, data concerning groundwater quality in this part of the Lake Chad is sparse and predications on water quality uncertain. Collecting more data about the confined Neogene aquifer in case of unsuitability of the lower part of the Quaternary deposits is recommended.

6. Acknowledgment

The authors thank the colleagues from the NGOs Oxfam, Action contre la faim (ACF), and Help-Chad as well as UNICEF and the staff of the Project ResEau of the Swiss co-operation for their support during the field mission and other logistics. Without their help this scientific mission would have not been possible.

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8. Annex I: Spatial distribution of hydrochemistry

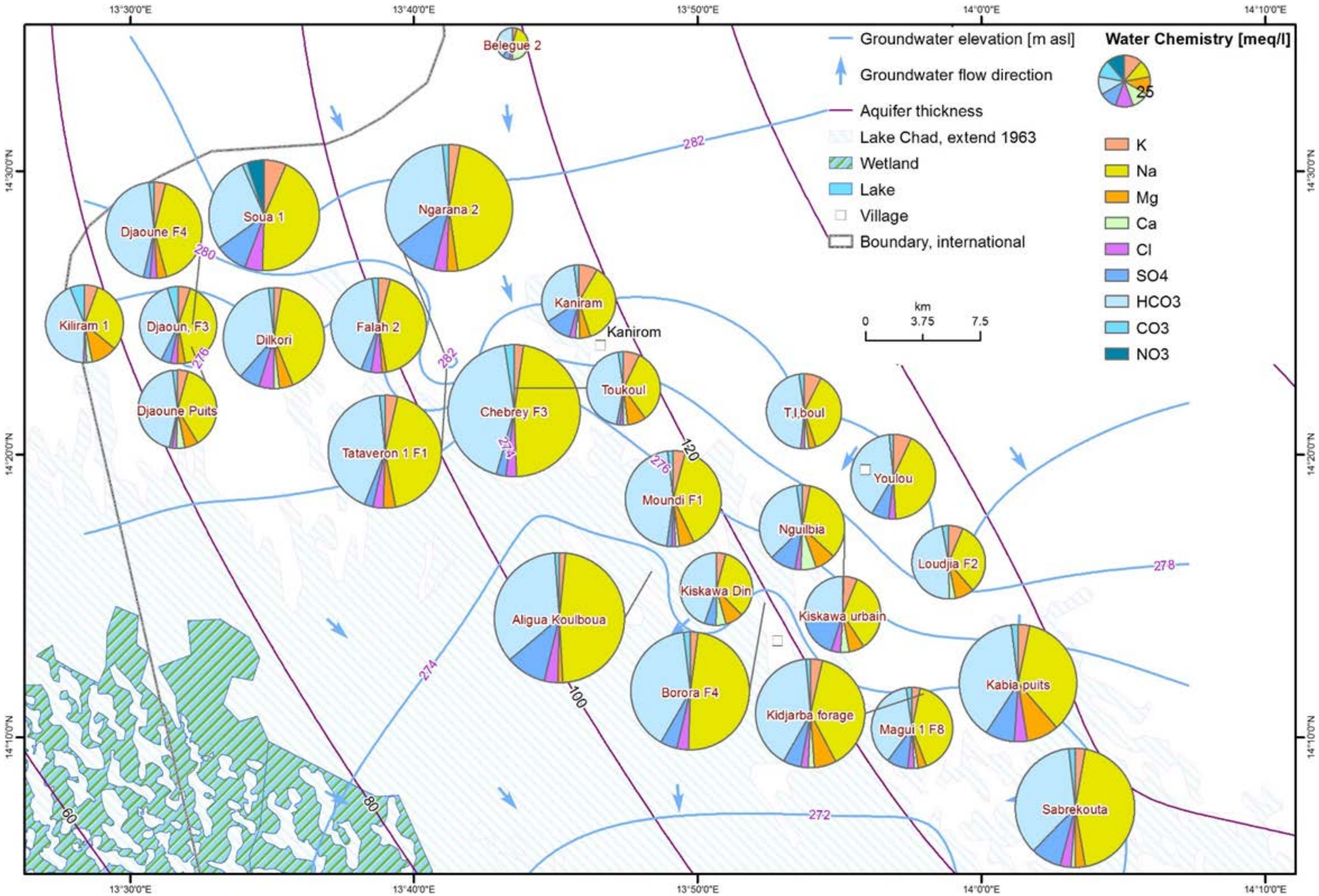

Figure 18: Pie charts of major ions characterizing the spatial distribution of groundwater chemistry within the northern sub-area. The size of pie charts is proportional to the concentration of dissolved solids.

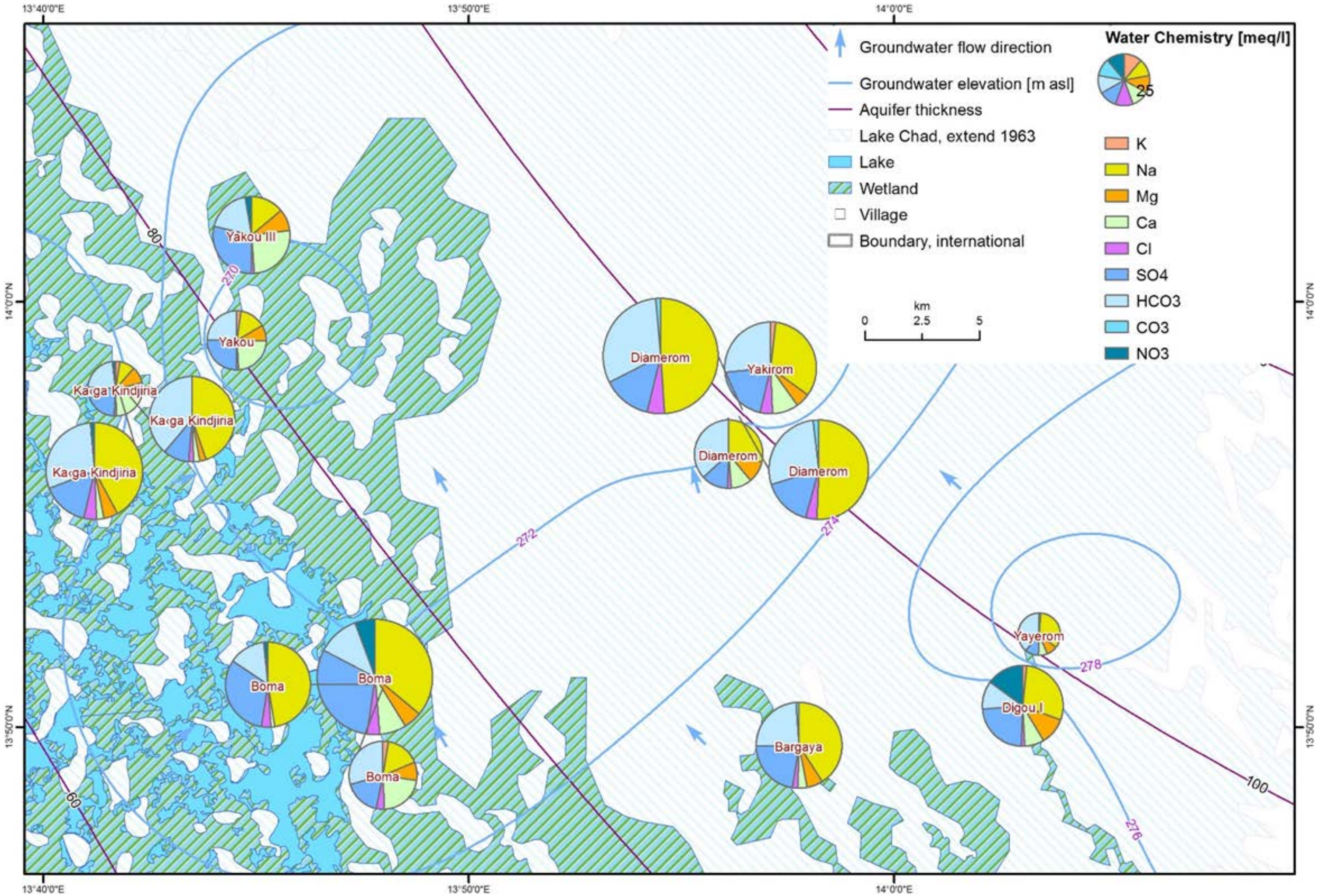

Figure 19: Pie charts of major ions characterizing the spatial distribution of groundwater chemistry within the central sub-area. The size of pie charts is proportional to the concentration of dissolved solids.

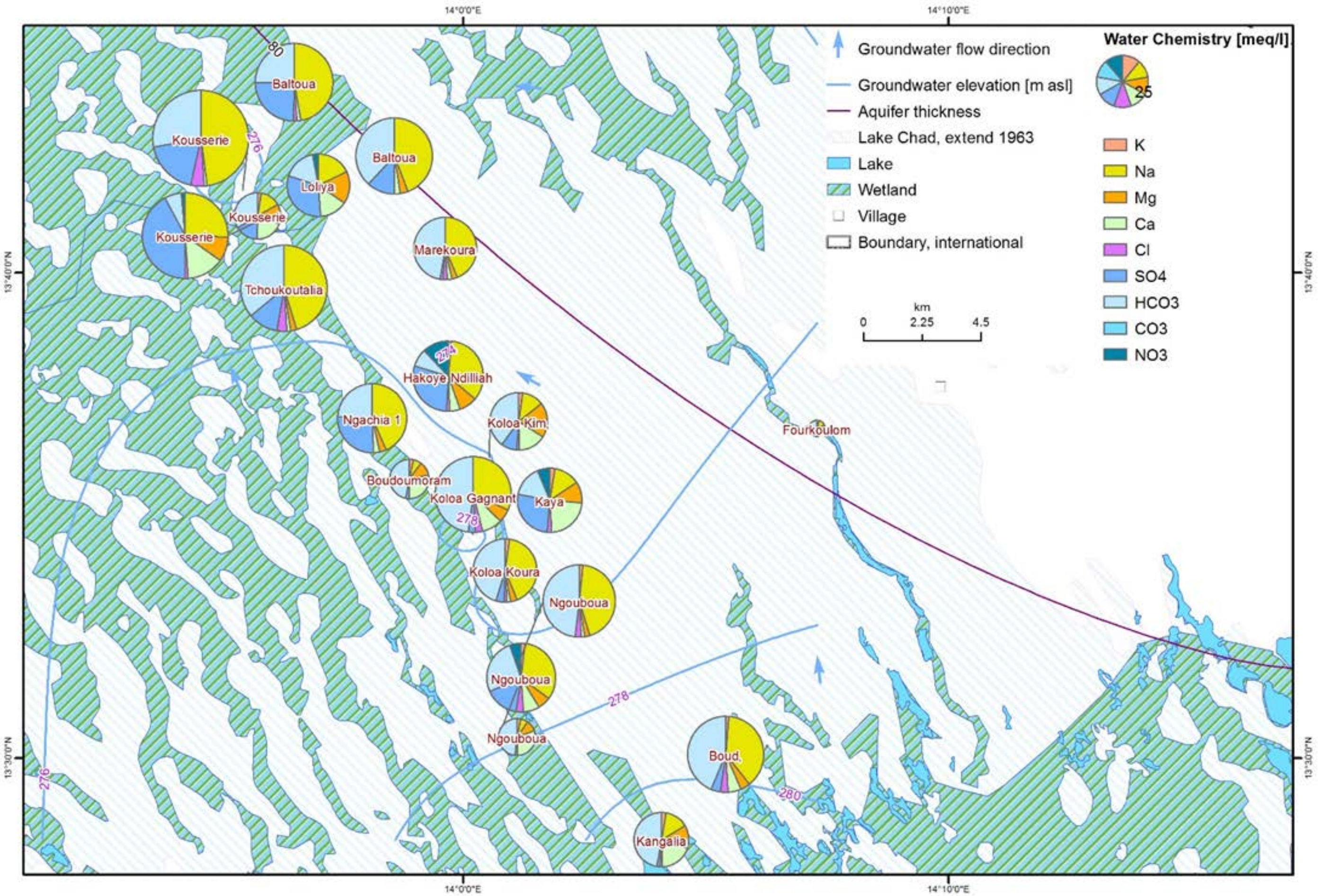

Figure 20: Pie charts of major ions characterizing the spatial distribution of groundwater chemistry within the southern sub-area. The size of pie charts is proportional to the concentration of dissolved solids.

9. Annex II: List of sampling locations

ID	Group	Name	Well Type	Sub-area	Sampling date	Longitude	Latitude	Elevation (m asl)	Drilling depth (m)	Depth to gw-table (m)
LAC-Eq$_1$-AQ-01	3	Baltoua	Drilled well, hand pump	south	07.02.2017	13.97008	13.70688	283	19.4	1.6
LAC-Eq$_1$-AQ-02	3	Loliya	Drilled well, hand pump	south	07.02.2017	13.94748	13.69679	287	17	7.94
LAC-Eq$_1$-AQ-03	3	Tchoukoutalia	Drilled well, hand pump	south	08.02.2017	13.9386	13.67557	279		
LAC-Eq$_1$-AQ-04	3	Kousserie	Drilled well, hand pump	south	08.02.2017	13.93271	13.686	279	16.6	7.92
LAC-Eq$_1$-AQ-05	3	Kousserie	Drilled well, hand pump	south	08.02.2017	13.92441	13.69513	287	17.5	8.32
LAC-Eq$_1$-AQ-06	3	Kousserie	Drilled well, hand pump	south	08.02.2017	13.92948	13.68628	281	15	8.39
LAC-Eq$_1$-AQ-07	3	Baltoua	Drilled well, hand pump	south	08.02.2017	13.94204	13.73219	281	15.58	9.7
LAC-Eq$_1$-AQ-08	3	Marekoura	Drilled well, hand pump	south	08.02.2017	13.99393	13.67508	278	18.4	1.4
LAC-Eq$_1$-AQ-09	3	Boudoumoram	Drilled well, hand pump	south	09.02.2017	13.98568	13.60238	285	17	8.54
LAC-Eq$_1$-AQ-10	3	Ngachia 1	Drilled well, hand pump	south	09.02.2017	13.97272	13.61673	280	17	6
LAC-Eq$_1$-AQ-11	3	Kaya	Drilled well, hand pump	south	09.02.2017	14.01609	13.58668	295	2	1
LAC-Eq$_1$-AQ-12	3	Hakoye Ndilliah	Drilled well, hand pump	south	10.02.2017	13.99496	13.63119	280	19.3	9.8
LAC-Eq$_1$-AQ-13	3	Koloa Kimé	Drilled well, hand pump	south	10.02.2017	14.00903	13.60343	281	16	9.1
LAC-Eq$_1$-AQ-14	3	Koloa Gagnant	Drilled well, hand pump	south	10.02.2017	14.00351	13.57693	284	16	7.79

ID	Group	Name	Well Type	Sub-area	Sampling date	Longitude	Latitude	Elevation (m asl)	Drilling depth (m)	Depth to gw-table (m)
LAC-Eq_1-AQ-15	3	Koloa Koura	Drilled well, hand pump	south	10.02.2017	14.0144	13.56447	290	17.7	7.39
LAC-Eq_1-AQ-16	3	Ngouboua	Drilled well, hand pump	south	10.02.2017	14.01901	13.53257	282		
LAC-Eq_1-AQ-17	3	Ngouboua	Drilled well,motorised	south	10.02.2017	14.01854	13.5242	280		
LAC-Eq_1-AQ-18	3	Ngouboua	Drilled well, hand pump	south	11.02.2017	14.01994	13.52766	277		
LAC-Eq_1-AQ-19	3	Kangalia	Drilled well, hand pump	south	11.02.2017	14.06809	13.47206	292	17	2.5
LAC-Eq_1-AQ-20	3	Boudé	Drilled well, hand pump	south	11.02.2017	14.09011	13.50136	292		
LAC-Eq_1-RIV-01	4	Fourkoulom	Lake	south	13.02.2017	14.12142	13.61329	276		
LAC-Eq_2-AQ-01	2	Yakou	Hand-dug well	centre	07.02.2017	13.74243	13.98499	267	6.7	6
LAC-Eq_2-AQ-02	2	Kaïga Kindjiria	Drilled well, hand pump	centre	07.02.2017	13.69664	13.96376	281	18	1
LAC-Eq_2-AQ-03	2	Kaïga Kindjiria	Drilled well, hand pump	centre	07.02.2017	13.69921	13.9646	282	18	1.5
LAC-Eq_2-AQ-04	2	Kaïga Kindjiria	Hand-dug well	centre	07.02.2017	13.69487	13.96597	281	6.5	6
LAC-Eq_2-AQ-05	2	Diamerom	Drilled well, hand pump	centre	08.02.2017	13.93925	13.95507	279	33	12
LAC-Eq_2-AQ-06	2	Diamerom	Hand-dug well	centre	08.02.2017	13.94053	13.95789	271	7.65	7
LAC-Eq_2-AQ-07	2	Diamerom	Drilled well, hand pump	centre	08.02.2017	13.93516	13.95457	283	21	1
LAC-Eq_2-AQ-08	2	Boma	Hand-dug well	centre	08.02.2017	13.7954	13.85003	276	3	2
LAC-Eq_2-AQ-09	2	Boma	Drilled well, hand pump	centre	08.02.2017	13.79971	13.84881	281	18	12
LAC-Eq_2-AQ-10	2	Boma	Drilled well, hand pump	centre	08.02.2017	13.79656	13.85302	304	18.8	14.28

ID	Group	Name	Well Type	Sub-area	Sampling date	Longitude	Latitude	Elevation (m asl)	Drilling depth (m)	Depth to gw-table (m)
LAC-Eq2-AQ-11	2	Yakirom	Hand-dug well	centre	09.02.2017	13.95156	13.97422	260	7.5	7
LAC-Eq2-AQ-12	2	Yakou III	Drilled well, hand pump	centre	09.02.2017	13.7482	14.02623	286	21	12
LAC-Eq2-AQ-13	2	Digou I	Hand-dug well	centre	09.02.2017	14.05042	13.84169	286	4	3
LAC-Eq2-AQ-14	2	Yayerom	Hand-dug well	centre	10.02.2017	14.05687	13.86973	294	7.8	7
LAC-Eq2-AQ-15	2	Karamga	Drilled well, hand pump	centre	10.02.2017	13.96274	13.82646	307	2.8	8.83
LAC-Eq2-AQ-16	2	Bargaya	Hand-dug well	north	07.02.2017	13.96275	13.82621	276	4.73	4.35
Lac 1	1	Djaoune Puits	Drilled well	north	08.02.2017	13.53595	14.39656	296	2	1.41
Lac 10	1	Toukoul	Drilled well	north	08.02.2017	13.72621	14.37225	302	28	12.67
Lac 11	1	Kaniram	Hand-dug well	north	09.02.2017	13.76337	14.40154	287	7.55	7.2
Lac 12	1	Belegue 2	Drilled well	north	10.02.2017	13.72445	14.57874	290	21	11.4
Lac 13	1	Ngarana 2	Drilled well	north	08.02.2017	13.6872	14.38629	284	21	11.36
Lac 14	1	Aligua Koulboua	Drilled well	north	10.02.2017	13.8061	14.26449	295	21	12.64
Lac 15	1	Kiskawa Din	Drilled well	north	10.02.2017	13.84424	14.25498	300	21	12.58
Lac 16	1	Borora F4	Drilled well	north	10.02.2017	13.87258	14.24608	305	18	13.87
Lac 17	1	Moundi F1	Drilled well	north	11.02.2017	13.81899	14.3074	294		
Lac 18	1	Kidjarba forage	Drilled well	north	12.02.2016	13.96567	14.19227	283	18	16
Lac 19	1	Magui 1 F8	Drilled well	north	12.02.2017	13.98035	14.17236	296	23.8	18.87
Lac 2	1	Djaoune F4	Drilled well	north	07.02.2017	13.53661	14.4102	282		
Lac 20	1	Kabia puits	Hand-dug well	north	12.02.2016	14.02139	14.17459	287	7	6.2
Lac 21	1	Sabrekouta	Hand-dug well	north	13.02.2017	14.05502	14.1254	269	6	5.8
Lac 22	1	Loudjia F2	Drilled well	north	13.02.2017	13.98065	14.279	288	23	16.37
Lac 23	1	Nguilbia	Drilled well	north	12.02.2017	13.91849	14.2392	300	22	17.86

ID	Group	Name	Well Type	Sub-area	Sampling date	Longitude	Latitude	Elevation (m asl)	Drilling depth (m)	Depth to gw-table (m)
Lac 24	1	Téléboul	Hand-dug well	north	12.02.2017	13.89575	14.35881	279	4.4	3.9
Lac 25	1	Youlou	Hand-dug well	north	12.02.2017	13.94824	14.3202	274		
Lac 26	1	Kiskawa urbain	Drilled well	north	14.02.2017	13.91849	14.23918	276		
Lac 3	1	Djaouné F3	Drilled well	north	07.02.2017	13.53828	14.40954	279	15	1.3
Lac 4	1	Kiliram 1	Hand-dug well	north	07.02.2017	13.47316	14.41019	285	4.2	3.2
Lac 5	1	Soua 1	Hand-dug well	north	07.02.2017	13.57862	14.47404	298	5.2	4.28
Lac 6	1	Dilkori	Drilled well	north	08.02.2017	13.60186	14.40177	296	21	13.98
Lac 7	1	Falah 2	Drilled well	north	08.02.2017	13.64586	14.40935	278	2	14.32
Lac 8	1	Tataveron 1 F1	Drilled well	north	08.02.2017	13.68584	14.38388	283		
Lac 9	1	Chebrey F3	Drilled well	north	08.02.2017	13.72546	14.35917	297	18	13.87

10. Annex III: List of measured chemical parameters (stable isotopes in ‰ VSMOW, concentrations in mg/l)

ID	pH	EC (µS/cm)	Oxygen-18	Deuterium	K	Na	Cl	Mg	Ca	SO_4	HCO_3
LAC-Eq_1-AQ-01	7.78	2460	2.32	9.4	13.4	549	18.9	22.5	25.3	311	1260
LAC-Eq_1-AQ-02	7.79	1661	2.73	8.8	6.2	150	7.06	74.5	105	545	384
LAC-Eq_1-AQ-03	7.62	3160	2.04	6.3	21.3	723	91.7	19.3	19.3	379	1520
LAC-Eq_1-AQ-04	7.35	3070	2.29	8.4	16.0	404	28.6	78.0	194	1392	270
LAC-Eq_1-AQ-05	7.82	3960	1.37	-0.3	11.9	945	136	8.52	17.9	774	1455
LAC-Eq_1-AQ-06	7.36	920	2.33	8.1	18.5	63.8	4.52	33.4	78.7	154	405
LAC-Eq_1-AQ-07	8.06	2700	1.56	5.6	4.4	612	26.6	4.33	18.0	664	865
LAC-Eq_1-AQ-08	7.71	1661	2.72	12.7	10.9	370	32.0	12.7	17.7	25.9	1058
LAC-Eq_1-AQ-09	7.28	658	2.22	10.1	17.4	22.4	0.75	20.1	82.3	18.9	413
LAC-Eq_1-AQ-10	7.74	2140	2.02	7.9	11.0	444	9.00	17.3	25.4	565	656
LAC-Eq_1-AQ-11	7.32	1777	3.00	11.8	35.0	116	32.1	51.1	179	497	371
LAC-Eq_1-AQ-12	8.05	2350	1.62	5.8	21.2	375	24.5	47.6	45.1	645	238
LAC-Eq_1-AQ-13	7.36	1330	2.14	7.4	24.0	85.7	18.7	75.1	97.8	131	757
LAC-Eq_1-AQ-14	7.09	2510	2.49	6.1	16.2	392	57.9	37.1	95.0	76.4	1577
LAC-Eq_1-AQ-15	7.48	1737	1.78	6.5	28.2	365	21.7	15.4	13.4	74.7	1053

ID	pH	EC (µS/cm)	Oxygen-18	Deuterium	K	Na	Cl	Mg	Ca	SO_4	HCO_3
LAC-Eq_1-AQ-16	7.87	2190	2.55	9.1	27.4	496	48.5	13.3	14.9	2.48	1446
LAC-Eq_1-AQ-17	7.11	604	2.91	12.7	14.0	18.9	1.51	15.5	77.3	13.6	376
LAC-Eq_1-AQ-18	7.64	2130	2.03	9.6	27.6	342	53.8	32.3	69.4	342	705
LAC-Eq_1-AQ-19	7.18	1241	2.27	12.2	24.6	89.6	12.4	46.8	111	26.2	809
LAC-Eq_1-AQ-20	7.38	2410	2.32	8.8	25.3	478	63.0	26.7	62.2	105	1455
LAC-Eq_1-RIV-01	7.61	121	1.80	8.3	3.7	7.8	0.05	3.96	10.0	0.044	73.1
LAC-Eq_2-AQ-01	6.88	1495	4.12	16.4	26.9	108	14.8	35.3	157	402	496
LAC-Eq_2-AQ-02	7.63	3920	2.07	6.5	11.6	851	133	50.0	44.4	658	1577
LAC-Eq_2-AQ-03	7.82	3030	4.65	25.6	6.1	704	47.7	18.9	32.6	323	1624
LAC-Eq_2-AQ-04	7.18	1277	5.55	23.8	25.2	57.7	13.3	34.0	160	343	376
LAC-Eq_2-AQ-05	8.44	4090	4.44	18.9	6.9	1076	120	3.00	3.65	704	1573
LAC-Eq_2-AQ-06	8.21	5510	2.99	10.7	10.0	1386	212	7.42	11.8	812	2333
LAC-Eq_2-AQ-07	7.66	1961	4.96	24.9	12.0	285	27.6	53.6	85.3	267	968
LAC-Eq_2-AQ-08	8.21	3410	1.62	4.5	5.5	734	87.1	5.41	20.1	1033	572
LAC-Eq_2-AQ-09	7.24	1930	4.53	18.5	38.7	163	60.8	45.5	192	367	779
LAC-Eq_2-AQ-10	7.39	5590	0.84	-0.3	27.4	1039	159	76.1	189	1829	890
LAC-Eq_2-AQ-11	7.59	3480	2.85	10.7	51.6	603	123	48.7	145	752	1284

ID	pH	EC (µS/cm)	Oxygen-18	Deuterium	K	Na	Cl	Mg	Ca	SO_4	HCO_3
LAC-Eq2-AQ-12	7.23	2400	6.13	22.7	17.4	178	25.1	61.8	289	765	632
LAC-Eq2-AQ-13	8.08	2940	1.89	4.9	31.9	410	27.7	80.2	96.7	681	423
LAC-Eq2-AQ-14	8.09	809	2.88	10.8	6.28	132	3.85	16.8	23.1	83.2	396
LAC-Eq2-AQ-15			3.91	14.1							
LAC-Eq2-AQ-16	7.57	3030	2.68	9.8	22.8	648	48.5	51.4	47.3	744	1011
Lac 1	7.69	2510	10.01	49.4	85.5	496	36.3	40.2	39.5	32.9	1570
Lac 10	7.7	2260	10.88	55.5	125	389	27.4	50.5	18.9	38.6	1383
Lac 11	7.97	2360	9.15	45.1	148	422	46.5	29.7	18.4	282	986
Lac 12	7.59	462	-5.17	-35.8	14.8	49.7	9.54	5.78	33.7	34.0	225
Lac 13	7.99	6400	4.48	17.2	149	1569	178	50.7	7.91	809	3093
Lac 14	7.93	6660	3.88	14.2	81.1	1745	191	23.1	8.43	768	3387
Lac 15	7.44	2160	7.23	36.9	70.6	380	11.7	48.6	44.6	121	1342
Lac 16	8.11	5320	0.81	-1.1	98.0	1457	146	6.26	4.67	288	3195
Lac 17	7.75	3710	7.08	36.8	121	781	41.4	52.3	22.1	69.3	2423
Lac 18	7.7	4550	5.13	22.5	141	995	86.1	89.2	40.9	290	2763
Lac 19	8	2820	3.98	17.5	69.2	589	57.7	25.0	20.2	253	1427
Lac 2	7.94	3820	3.12	13.2	116	839	70.1	34.0	13.3	94.0	2355
Lac 20	7.5	5760	5.43	22.4	144	1040	165	138	25.9	492	3052
Lac 21	7.87	5550	2.32	7.8	130	1371	137	44.8	32.1	533	2937
Lac 22	7.55	2870	12.91	66.8	112	373	11.5	50.7	28.5	5.74	1447
Lac 23	7.58	2910	8.68	44.1	71.7	526	54.2	64.2	81.0	321	1461
Lac 24	7.84	2430	12.53	63.7	136	452	31.0	19.8	18.7	19.8	1482
Lac 25	8.16	3130	11.83	59.7	160	648	64.7	5.09	10.1	210	1620
Lac 26	7.72	2510	-2.24	-19.4	118	430	77.5	43.0	40.0	526	819
Lac 3	7.97	2500	-0.56	-8.5	97.0	538	57.0	22.1	11.1	108	1296

ID	pH	EC (μS/cm)	Oxygen-18	Deuterium	K	Na	Cl	Mg	Ca	SO_4	HCO_3
Lac 4	7.56	2560	9.89	52.9	110	399	26.0	74.7	27.9	3.53	1503
Lac 5	8.22	5210	4.41	17.5	257	1148	208	12.8	20.1	509	1957
Lac 6	7.72	4290	2.71	7.3	80.2	920	166	51.6	33.1	306	2164
Lac 7	8.2	3840	4.29	19.5	114	846	113	17.5	6.83	136	2156
Lac 8	7.82	4880	3.47	15.1	153	1200	128	50.1	11.7	147	3118
Lac 9	8.29	6990	8.64	43.8	129	1768	154	16.9	3.36	180	4301

ID	Fe(II)	Mn	NO_3	Br	NH_4	NO_2	F	PO_4	Al	As	BO_2	Ba
LAC-Eq1-AQ-01	0.307	0.121	0.08	0.28	0.33	-0.03	0.81	0.56	0.014	-0.02	0.77	0.059
LAC-Eq1-AQ-02	0.057	0.273	67.7	0.37	0.04	2.38	0.31	0.13	0.004	-0.02	0.20	0.047
LAC-Eq1-AQ-03	0.336	0.057	0.71	0.94	1.37	0.04	0.45	1.08	0.005	-0.02	0.98	0.045
LAC-Eq1-AQ-04	0.165	0.545	61.7	0.79	0.84	0.35	0.86	0.20	0.005	0.02	0.44	0.023
LAC-Eq1-AQ-05	0.039	0.058	0.03	0.88	0.12	-0.03	0.35	0.58	0.007	-0.02	0.90	0.058
LAC-Eq1-AQ-06	0.681	0.120	6.47	0.199	0.01	0.042	0.413	0.87	0.004	0.04	0.21	0.085
LAC-Eq1-AQ-07	0.037	0.032	3.76	0.57	0.01	0.41	0.28	0.59	0.006	-0.02	0.54	0.034
LAC-Eq1-AQ-08	0.137	0.107	0.05	0.24	0.52	-0.03	0.63	0.80	0.005	-0.02	0.50	0.032
LAC-Eq1-AQ-09	0.185	0.219	0.007	0.033	1.57	-0.003	0.265	1.98	0.004	-0.02	0.08	0.068
LAC-Eq1-AQ-10	0.109	0.108	-0.03	0.31	0.34	-0.03	0.88	2.78	0.012	-0.02	0.47	0.045
LAC-Eq1-AQ-11	0.009	0.211	155	0.51	0.01	0.25	0.51	0.22	0.004	-0.02	0.24	0.094

ID	Fe(II)	Mn	NO_3	Br	NH_4	NO_2	F	PO_4	Al	As	BO_2	Ba
LAC-Eq_1-AQ-12	0.010	0.080	345	0.67	0.01	8.49	1.75	0.18	0.012	-0.02	0.08	0.109
LAC-Eq_1-AQ-13	0.673	0.482	0.30	0.31	0.81	-0.03	0.68	0.26	0.008	-0.02	0.14	0.158
LAC-Eq_1-AQ-14	2.25	0.509	0.06	0.60	41.6	-0.03	0.67	2.23	0.009	-0.02	0.71	0.581
LAC-Eq_1-AQ-15	0.194	0.094	-0.03	0.19	1.57	-0.03	0.91	0.82	0.007	-0.02	0.68	0.053
LAC-Eq_1-AQ-16	0.179	0.039	-0.03	0.30	1.28	-0.03	2.31	1.62	0.012	-0.02	1.03	0.113
LAC-Eq_1-AQ-17	0.541	2.17	0.048	0.042	1.21	0.005	0.475	2.13	0.008	-0.02	0.01	0.092
LAC-Eq_1-AQ-18	0.152	0.150	150	0.49	0.30	0.35	1.75	1.17	0.005	-0.02	0.32	0.127
LAC-Eq_1-AQ-19	0.854	0.210	-0.03	0.16	1.50	-0.03	0.67	0.27	0.005	-0.02	0.13	0.950
LAC-Eq_1-AQ-20	0.280	0.110	0.03	0.59	3.47	-0.03	0.91	0.51	0.010	-0.02	0.27	0.271
LAC-Eq_1-RIV-01	0.095	0.015	0.004	-0.003	0.06	0.008	0.267	0.08	0.030	-0.02	-0.01	0.065
LAC-Eq_2-AQ-01	0.023	1.51	0.27	0.79	0.94	0.09	0.18	4.64	0.017	-0.02	0.21	0.184
LAC-Eq_2-AQ-02	0.101	0.057	74.9	2.34	0.09	0.24	0.53	0.52	0.025	-0.02	0.64	0.072
LAC-Eq_2-AQ-03	0.855	0.147	2.59	0.28	0.06	0.86	0.28	1.00	0.637	-0.02	0.68	0.086
LAC-Eq_2-AQ-04	0.815	0.155	35.0	0.44	0.11	0.72	0.11	6.60	0.552	-0.02	0.35	0.224
LAC-Eq_2-AQ-05	0.251	0.036	0.06	0.78	0.08	-0.03	0.54	1.53	0.166	-0.02	0.99	0.023
LAC-Eq_2-AQ-06	0.526	0.072	4.07	1.28	0.15	1.00	0.66	1.90	0.385	0.08	1.19	0.033
LAC-Eq_2-AQ-07	0.149	0.384	9.88	0.41	13.8	2.35	0.76	3.06	0.105	-0.02	0.44	0.514
LAC-Eq_2-AQ-08	0.039	0.019	68.2	0.86	0.01	1.48	0.17	0.29	0.014	-0.02	0.51	0.037

ID	Fe(II)	Mn	NO_3	Br	NH_4	NO_2	F	PO_4	Al	As	BO_2	Ba
LAC-Eq2-AQ-09	0.632	1.02	1.72	1.35	0.02	1.33	0.24	7.97	0.128	-0.02	0.29	0.255
LAC-Eq2-AQ-10	0.011	0.361	440	3.61	0.32	0.73	0.20	0.56	-0.003	0.10	0.50	0.038
LAC-Eq2-AQ-11	0.304	0.299	0.09	0.92	0.23	-0.03	0.81	1.13	0.016	-0.02	0.66	0.074
LAC-Eq2-AQ-12	0.029	0.575	92.7	1.81	0.13	0.60	0.25	1.33	0.013	-0.02	0.51	0.066
LAC-Eq2-AQ-13	0.025	0.154	568	0.67	0.01	2.21	0.69	0.33	0.013	-0.02	0.27	0.145
LAC-Eq2-AQ-14	1.20	0.113	7.63	0.107	0.02	-0.003	1.48	1.47	0.859	0.06	0.26	0.087
LAC-Eq2-AQ-15												
LAC-Eq2-AQ-16	0.162	0.258	1.90	0.57	0.34	0.29	0.56	0.75	0.025	-0.02	0.50	0.091
Lac 1	0.143	0.198	8.08	0.97	9.77	1.37	2.04	3.46	0.008	-0.02	1.28	0.205
Lac 10	0.035	0.052	0.04	0.54	8.11	-0.003	1.16	4.64	0.004	-0.02	1.46	0.078
Lac 11	0.030	0.011	31.4	0.56	4.28	1.44	4.02	4.95	0.007	-0.02	1.17	0.090
Lac 12	0.048	0.041	0.697	0.090	0.34	0.343	0.549	0.71	0.007	-0.02	0.05	0.026
Lac 13	0.054	0.044	4.50	2.78	4.64	1.39	2.76	3.69	0.008	0.04	2.26	0.104
Lac 14	0.702	0.267	0.14	2.52	3.84	6.40	2.93	5.48	0.014	-0.02	2.50	0.194
Lac 15	0.136	0.376	0.05	0.40	8.42	0.15	0.88	2.33	0.005	-0.02	0.98	0.072
Lac 16	0.559	0.191	6.72	1.35	8.57	19.6	3.66	9.30	0.027	-0.02	2.98	0.213
Lac 17	0.287	0.053	0.03	0.61	4.37	-0.03	1.80	2.45	0.006	-0.02	1.54	0.106
Lac 18	0.136	0.061	0.27	1.29	5.47	2.07	3.00	3.16	0.005	-0.02	1.43	0.388
Lac 19	0.130	0.077	0.21	0.62	2.33	1.76	1.15	2.98	0.004	-0.02	0.72	0.036
Lac 2	0.062	0.023	1.79	0.95	4.42	1.27	1.76	3.51	0.007	-0.02	1.13	0.061
Lac 20	0.042	0.198	30.2	2.33	135	10.7	1.51	6.96	0.010	-0.02	1.98	0.305
Lac 21	0.196	0.155	-0.03	1.57	1.75	-0.03	3.74	4.07	0.032	0.05	0.97	0.144
Lac 22	0.319	0.103	0.08	0.34	9.50	0.18	1.72	4.75	0.030	-0.02	1.42	0.089
Lac 23	0.261	0.186	0.73	1.03	10.4	8.17	1.12	1.94	0.023	-0.02	0.69	0.093

ID	Fe(II)	Mn	NO_3	Br	NH_4	NO_2	F	PO_4	Al	As	BO_2	Ba
Lac 24	0.529	0.181	1.66	0.44	1.35	1.59	2.41	6.54	0.288	-0.02	1.40	0.239
Lac 25	0.228	0.063	0.06	0.97	2.29	2.08	3.30	6.57	0.113	-0.02	1.34	0.224
Lac 26	0.024	0.078	3.43	0.61	2.38	0.20	1.34	2.15	0.004	-0.02	0.49	0.119
Lac 3	0.055	0.026	9.09	0.70	13.0	2.86	2.53	3.03	0.008	-0.02	0.95	0.067
Lac 4	0.099	0.105	9.51	0.75	29.8	1.35	2.56	6.58	0.011	-0.02	1.82	0.522
Lac 5	0.050	0.022	352	2.01	0.35	1.26	6.06	8.04	0.020	0.19	0.85	0.200
Lac 6	0.162	0.182	0.36	1.27	1.35	0.37	0.90	1.33	0.004	-0.02	0.66	0.678
Lac 7	0.063	0.112	0.21	0.95	7.23	0.03	3.19	4.61	0.009	-0.02	1.26	0.034
Lac 8	0.322	0.077	0.09	1.61	10.5	0.63	1.09	3.64	0.017	-0.02	1.65	0.173
Lac 9	0.204	0.017	0.30	2.07	0.26	0.40	5.38	15.3	0.011	-0.02	2.76	0.055

ID	Be	Cd	Co	Cr	Cu	Li	Ni	Pb	Sc	SiO_2	Sr	Ti
LAC-Eq_1-AQ-01	0.001	-0.002	-0.003	-0.003	-0.003	0.005	0.006	-0.02	0.001	66.4	0.288	0.002
LAC-Eq_1-AQ-02	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	0.003	-0.02	0.001	65.2	0.622	0.001
LAC-Eq_1-AQ-03	-0.001	-0.002	-0.003	-0.003	-0.003	0.007	0.003	-0.02	-0.001	78.7	0.296	0.001
LAC-Eq_1-AQ-04	-0.001	-0.002	-0.003	-0.003	0.003	0.009	0.003	-0.02	0.001	77.9	1.71	-0.001
LAC-Eq_1-AQ-05	-0.001	-0.002	-0.003	-0.003	-0.003	0.008	0.004	-0.02	-0.001	71.0	0.248	-0.001
LAC-Eq_1-AQ-06	-0.001	-0.002	-0.003	-0.003	0.004	0.006	-0.003	-0.02	-0.001	81.3	0.825	-0.001
LAC-Eq_1-AQ-07	-0.001	-0.002	-0.003	-0.003	0.003	0.005	0.004	-0.02	-0.001	72.0	0.174	-0.001
LAC-Eq_1-AQ-08	-0.001	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.02	-0.001	70.7	0.234	0.001
LAC-Eq_1-AQ-09	-0.001	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.02	-0.001	75.5	0.724	0.001
LAC-Eq_1-AQ-10	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	0.003	-0.02	-0.001	75.7	0.312	0.001

ID	Be	Cd	Co	Cr	Cu	Li	Ni	Pb	Sc	SiO_2	Sr	Ti
LAC-Eq_1-AQ-11	-0.001	-0.002	-0.003	-0.003	-0.003	0.012	-0.003	-0.02	-0.001	49.3	1.15	-0.001
LAC-Eq_1-AQ-12	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	0.003	-0.02	-0.001	46.9	0.837	0.001
LAC-Eq_1-AQ-13	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	-0.003	-0.02	-0.001	68.3	1.43	-0.001
LAC-Eq_1-AQ-14	-0.001	-0.002	-0.003	-0.003	-0.003	0.006	-0.003	-0.02	-0.001	88.4	0.943	-0.001
LAC-Eq_1-AQ-15	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	-0.003	-0.02	-0.001	69.0	0.293	0.001
LAC-Eq_1-AQ-16	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	-0.003	-0.02	-0.001	59.1	0.354	0.006
LAC-Eq_1-AQ-17	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	-0.003	-0.02	-0.001	69.7	0.574	0.001
LAC-Eq_1-AQ-18	-0.001	-0.002	-0.003	-0.003	0.003	0.009	0.003	-0.02	0.001	57.8	1.02	0.001
LAC-Eq_1-AQ-19	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	-0.003	-0.02	0.001	68.1	1.17	0.001
LAC-Eq_1-AQ-20	-0.001	-0.002	-0.003	-0.003	-0.003	0.009	-0.003	-0.02	-0.001	67.7	0.855	0.002
LAC-Eq_1-RIV-01	-0.001	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.02	-0.001	19.0	0.105	0.001
LAC-Eq_2-AQ-01	-0.001	-0.002	-0.003	-0.003	0.036	-0.003	0.033	-0.02	-0.001	62.9	0.912	0.002
LAC-Eq_2-AQ-02	-0.001	-0.002	-0.003	-0.003	-0.003	0.009	0.008	-0.02	-0.001	76.1	0.564	0.001
LAC-Eq_2-AQ-03	-0.001	-0.002	-0.003	-0.003	0.003	0.006	0.005	-0.02	0.001	88.6	0.325	0.006
LAC-Eq_2-AQ-04	-0.001	-0.002	-0.003	-0.003	0.018	-0.003	0.006	-0.02	0.001	71.2	0.911	0.012
LAC-Eq_2-AQ-05	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	0.007	-0.02	-0.001	67.4	0.104	0.007
LAC-Eq_2-AQ-06	-0.001	-0.002	-0.003	-0.003	0.003	0.007	0.009	-0.02	-0.001	68.2	0.178	0.010
LAC-Eq_2-AQ-07	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	0.003	-0.02	-0.001	100	0.895	0.003

ID	Be	Cd	Co	Cr	Cu	Li	Ni	Pb	Sc	SiO_2	Sr	Ti
LAC-Eq_2-AQ-08	-0.001	-0.002	-0.003	-0.003	-0.003	0.006	-0.003	-0.02	-0.001	66.5	0.236	0.001
LAC-Eq_2-AQ-09	-0.001	-0.002	-0.003	-0.003	0.007	0.006	0.008	-0.02	0.001	73.2	1.26	0.004
LAC-Eq_2-AQ-10	-0.001	-0.002	-0.003	-0.003	0.008	0.024	0.008	-0.02	0.001	53.2	1.60	-0.001
LAC-Eq_2-AQ-11	-0.001	-0.002	-0.003	-0.003	-0.003	0.006	-0.003	-0.02	0.001	81.6	1.96	0.001
LAC-Eq_2-AQ-12	-0.001	-0.002	-0.003	-0.003	0.006	0.010	0.014	-0.02	0.001	68.1	1.73	0.001
LAC-Eq_2-AQ-13	-0.001	-0.002	-0.003	-0.003	0.007	0.007	-0.003	-0.02	-0.001	61.5	1.52	0.001
LAC-Eq_2-AQ-14	-0.001	-0.002	-0.003	-0.003	0.004	0.004	0.004	-0.02	0.001	73.4	0.252	0.014
LAC-Eq_2-AQ-15												
LAC-Eq_2-AQ-16	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	0.004	-0.02	0.001	63.4	0.633	0.001
Lac 1	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	-0.003	-0.02	-0.001	72.3	0.646	0.002
Lac 10	-0.001	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.02	-0.001	75.6	0.803	0.001
Lac 11	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	-0.003	-0.02	-0.001	54.6	0.588	0.003
Lac 12	-0.001	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.02	-0.001	73.7	0.308	0.001
Lac 13	-0.001	-0.002	-0.003	-0.003	0.003	0.006	0.005	-0.02	-0.001	54.0	1.01	0.006
Lac 14	-0.001	-0.002	-0.003	-0.003	0.004	0.007	0.005	-0.02	-0.001	66.2	0.713	0.007
Lac 15	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	0.003	-0.02	-0.001	99.0	0.603	0.001
Lac 16	-0.001	-0.002	-0.003	0.005	-0.003	0.003	0.007	-0.02	-0.001	30.9	0.085	0.029
Lac 17	-0.001	-0.002	-0.003	-0.003	-0.003	0.005	-0.003	-0.02	-0.001	74.8	1.15	0.011
Lac 18	-0.001	-0.002	-0.003	-0.003	0.009	0.004	0.004	-0.02	0.001	63.1	1.63	0.006
Lac 19	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	-0.003	-0.02	-0.001	69.4	0.430	0.002
Lac 2	-0.001	-0.002	-0.003	-0.003	0.005	0.004	-0.003	-0.02	-0.001	67.6	0.960	0.005
Lac 20	-0.001	-0.002	-0.003	-0.003	-0.003	0.010	0.004	-0.02	0.001	109	1.57	0.001
Lac 21	-0.001	-0.002	-0.003	-0.003	-0.003	0.008	0.004	-0.02	-0.001	69.8	0.681	0.003

ID	Be	Cd	Co	Cr	Cu	Li	Ni	Pb	Sc	SiO_2	Sr	Ti
Lac 22	-0.001	-0.002	-0.003	0.003	-0.003	0.012	-0.003	-0.02	-0.001	71.7	0.953	0.002
Lac 23	-0.001	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.02	0.001	63.8	1.72	0.001
Lac 24	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	0.003	-0.02	0.001	107	0.430	0.006
Lac 25	-0.001	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.02	0.001	69.8	0.218	0.008
Lac 26	-0.001	-0.002	-0.003	-0.003	-0.003	0.004	-0.003	-0.02	-0.001	67.1	1.08	0.001
Lac 3	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	-0.003	-0.02	-0.001	71.5	0.614	0.003
Lac 4	-0.001	-0.002	-0.003	-0.003	-0.003	0.005	0.003	-0.02	-0.001	137	1.14	0.001
Lac 5	-0.001	-0.002	-0.003	0.003	0.016	0.006	0.017	-0.02	-0.001	38.9	0.453	0.002
Lac 6	-0.001	-0.002	-0.003	-0.003	-0.003	0.006	-0.003	-0.02	-0.001	75.9	2.26	0.001
Lac 7	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	-0.003	-0.02	0.001	44.9	0.394	0.003
Lac 8	-0.001	-0.002	-0.003	0.003	0.008	0.007	-0.003	-0.02	-0.001	58.0	1.15	0.006
Lac 9	-0.001	-0.002	-0.003	-0.003	-0.003	0.003	0.003	-0.02	0.001	40.6	0.331	0.009

ID	V	Zn	CO_3	TIC	NPOC	TN
LAC-Eq_1-AQ-01	0.003	0.134		217	30.9	1.7
LAC-Eq_1-AQ-02	-0.003	0.207				
LAC-Eq_1-AQ-03	-0.003	0.024				
LAC-Eq_1-AQ-04	0.033	0.060				
LAC-Eq_1-AQ-05	-0.003	0.245				
LAC-Eq_1-AQ-06	0.009	0.027				
LAC-Eq_1-AQ-07	-0.003	0.166				
LAC-Eq_1-AQ-08	-0.003	0.080				
LAC-Eq_1-AQ-09	-0.003	0.529				

ID	V	Zn	CO_3	TIC	NPOC	TN
LAC-Eq_1-AQ-10	-0.003	0.179				
LAC-Eq_1-AQ-11	0.003	0.799				
LAC-Eq_1-AQ-12	-0.003	0.081				
LAC-Eq_1-AQ-13	0.004	0.769				
LAC-Eq_1-AQ-14	-0.003	1.86				
LAC-Eq_1-AQ-15	-0.003	0.541				
LAC-Eq_1-AQ-16	-0.003	0.009		261	23.0	1.7
LAC-Eq_1-AQ-17	0.004	0.021				
LAC-Eq_1-AQ-18	0.003	0.029				
LAC-Eq_1-AQ-19	-0.003	1.10				
LAC-Eq_1-AQ-20	-0.003	1.72				
LAC-Eq_1-RIV-01	-0.003	0.021				
LAC-Eq_2-AQ-01	0.021	0.015				
LAC-Eq_2-AQ-02	-0.003	0.082				
LAC-Eq_2-AQ-03	0.005	0.092				
LAC-Eq_2-AQ-04	0.037	0.004				
LAC-Eq_2-AQ-05	0.004	0.028	51.5	306	37.3	1.9
LAC-Eq_2-AQ-06	0.021	0.134	53.5	474	53.7	4.2

ID	V	Zn	CO_3	TIC	NPOC	TN
LAC-Eq2-AQ-07	0.005	0.007				
LAC-Eq2-AQ-08	0.027	0.047	17.3			
LAC-Eq2-AQ-09	0.012	0.011				
LAC-Eq2-AQ-10	0.017	0.351				
LAC-Eq2-AQ-11	-0.003	0.438				
LAC-Eq2-AQ-12	0.005	0.012		121	42.3	24.8
LAC-Eq2-AQ-13	-0.003	0.040				
LAC-Eq2-AQ-14	0.004	0.023				
LAC-Eq2-AQ-15						
LAC-Eq2-AQ-16	-0.003	0.433	22.8	201	27.2	2.0
Lac 1	-0.003	0.019	36.9	306	45.0	10.7
Lac 10	-0.003	0.005	38.3	262	33.2	6.3
Lac 11	0.004	0.021	32.9	198	23.6	9.0
Lac 12	0.007	-0.003		42.1	3.0	0.5
Lac 13	0.022	0.014	75.4	652	81.8	9.6
Lac 14	0.016	0.096	58.2	708	70.8	9.4
Lac 15	-0.003	0.014		233	35.7	7.0
Lac 16	0.045	0.303	71.1	666	75.9	16.9
Lac 17	0.011	0.094	51.8	495	53.7	6.1
Lac 18	0.013	0.412	45.8	566	68.8	9.2
Lac 19	-0.003	0.014	43.0	270	26.7	3.5
Lac 2	0.006	0.034	46.7	482	57.2	9.4
Lac 20	0.007	0.025	70.8	649	75.1	84.1

ID	V	Zn	CO_3	TIC	NPOC	TN
Lac 21	0.008	0.013	71.0	623	47.7	4.5
Lac 22	-0.003	0.007	45.2	282	51.4	9.2
Lac 23	-0.003	0.013	42.1	279	47.8	11.9
Lac 24	0.008	0.010	34.5	290	42.6	4.4
Lac 25	0.015	0.004	34.4	318	50.5	5.5
Lac 26	-0.003	0.171	16.1	162	10.0	2.4
Lac 3	0.004	0.004	76.6	257	31.6	12.3
Lac 4	0.003	0.011	106	324	48.2	22.8
Lac 5	0.299	0.023	54.2	392	48.6	125
Lac 6	-0.003	0.026	50.3	451	48.2	3.8
Lac 7	-0.003	0.050	57.8	438	30.7	2.9
Lac 8	0.007	0.194	55.3	639	66.1	11.2
Lac 9	0.028	0.028	115	911	95.1	10.4