Contribution of Hydrochemical and Isotopic Tracers to the Investigation of Water Resources in Ouham Watershed (Lake Chad Sub-basin)

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Abstract

The Central African Republic (CAR) occupies a strategic position in the Lake Chad basin since most of the water feeding the various tributaries of the Chari River, the principal water source for Lake Chad, comes from its territory. Indeed, the north of CAR, and in particular the Ouham prefecture, at the head of the entire endorheic watershed of Chad, benefits from favorable rainfall conditions. Sampling campaigns and in situ measurements were conducted for chemical and isotopic elements. The results show that the waters are relatively acidic, with pH ranges of 5.53 and 6.56 and low mineralization. The chemical type of the waters is bicarbonate, calcareous, and magnesian. The geochemical process is controlled by two mechanisms (i) 62% water/rock exchange and (ii) 38% precipitation water input. The values of log pCO_2 (0.06 atm or log $pCO_2 = -1.5$ atm) indicate that it is CO_2 contribution under open-system conditions to an unlimited gas reservoir, which is the soil atmosphere. The average contents are for oxygen-18 of -3.83 ± 0.2‰ and deuterium of -19.36 ± 0.9‰, with a deuterium excess of 10.99‰. The water table recharge is recent. It is done directly by precipitation infiltration without significant evaporation. This recent contribution of water is confirmed by SiO_2 and HCO_3- values, which are the essential components of the soluble load. Alkalis and alkaline piles of the earth (16% of the total weight), and finally, the low contents in anions (Cl^-, SO_4^{2-}), translate well to the exclusively crystalline character. The quality and the potential of groundwater as a water supply resource are confirmed, bearing in mind the local rainfall (1500 mm/year). Plus, indications of the possibility for the development of the exploitation are provided.

Keywords

Hydrochemistry · Geochemistry · Isotopes · Aquifer · Surface water · Watershed

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1 Introduction

The Central African Republic (CAR) occupies a strategic place in the Lake Chad basin since the Ouham province, in particular, is at the head of the entire endorheic watershed of Lake Chad. This area benefits from favorable rainfall conditions (1500 mm/year). But very little hydrological and hydrogeological knowledge is available for this locality. To this end, the contribution of hydrochemical and isotopic tracers (^{18}O and ^{2}H of the water molecule) proved to be the best approach to have a first diagnosis of the dynamics,

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the quality of available resources, the recharge processes, and the anthropic footprint on the aquifer (Bajjali, 2006; Edmunds et al., 2003; Yuan et al., 2017; Zagana et al., 2007). These data provide the necessary basis for groundwater pollution prevention and control. Additionally, it facilitates sustainable development (Tiwari et al., 2017; Yang et al., 2016). This study can also add value to hydrochemical research and groundwater quality assessment in other parts of the world.

2 Materials and Methods

The Ouham prefecture, bordering Chad, is located in the northern part of the country. With an area of 50,250 km^2, a tropical climate (Hot), a temperature between 27 and 32 °C, and rainfall of 1500 mm/year (Djebebe-Ndjiguim, 2014). To achieve the objectives set by this work, the main one being to acquire better knowledge and describe the hydrodynamic functioning of the aquifers of the Ouham region, we have reviewed bibliographic data but also conducted several field campaigns as well as field and laboratory analyses (Boulvert, 1982, 1987).

3 Results

3.1 Physicochemical Characterization of Water

The Quaternary aquifer conditions are contrasting concerning recharge and surface water–groundwater interaction. Moreover, given the extent of the sampling region, the physicochemical parameters reflect relatively low variability. Therefore, the most relevant parameter for comparison is probably electrical conductivity. The values range from 82.9 to 371 µS/cm for borehole water and 39.55 to 180 µS/cm for well water. Meanwhile, river water values are around 40 µS/cm because these waters are very shallow, and the humidity conditions are more favorable (Table 1).

On the other hand, the samples taken from the Ouham groundwater are more acidic. Results from the carbonic acid dissociation from CO_2 present in the atmosphere are one of the factors in the acidification of the groundwater concerned. In an open atmosphere, the abundance of CO_2 in the soil maintains an acidic pH. Whereas as soon as the environment closes (deep aquifer), the hydrolysis of carbonates and silicates consumes acidity, and the pH increases. In the boreholes, the pH tends toward neutrality (6.93) through equilibrium at the carbonate level. This region is hydraulically connected to crystalline aquifers in the subsoil. Furthermore, it is influenced by mixing with groundwater from weakly mineralized hard rocks.

The results are expressed as δ ‰ versus V-SMOW. They show that the stable isotope contents (^{18}O and ^{2}H) of Ouham groundwater range from − 22.967‰ to − 11.609‰ versus V-SMOW for deuterium and from − 4.633‰ to − 2.939‰ versus V-SMOW for oxygen-18.

4 Discussion

By alteration, the ions of silicate minerals (Na^+. Ca^{2+}. K^+. Mg^{2+}. and silica) of the reservoir rock in the Ouham region are released in solution and partly replaced by H^+ ions. Hydrolysis of silicates consumes l acidity, and pH increases (Djebebe-Ndjiguim, 2014). Unreplaced ions (aluminum. ferric iron, and part of the silica) recrystallize in place. The

Table 1 Statistical summary of the physicochemical parameters of the analyzed water points

Variable	Minimum	Maximum	Average	Median	SD	CV (%)
pH	5.5	6.9	6.1	6.1	0.3	6.3
EC (25 °C)	39.5	370.5	143.5	134.7	83.2	58.0
Ca^{2+}	0.5	39.1	5.6	3.8	7.1	127.7
Mg^{2+}	2.5	43.1	12.3	10.0	9.0	73.4
Na^+	2.08	19.0	9.0	8.9	4.4	49.6
K^+	0.47	6.6	2.8	2.7	1.5	53.8
HCO_3−	14.9	221.9	77.3	72.5	47.6	61.5
Cl^-	0.02	13.1	1.8	0.9	2.4	133.1
SO_4^{2}−	0.02	23.5	1.1	1.1	4.1	357.8
NO_3^-	0.02	29.3	4.8	2.0	7.0	145.6
SiO_2	1.5	18.6	11.6	12.9	4.8	41.9

Contents are expressed in mg/L, EC: electrical conductivity in µS/cm, CV: coefficient of variation in % and pH without unit, SD: standard deviation

general reaction reflecting the interactions of water and silicate rocks can be written (Berner et al., 1983) (reaction 1).

$$\text{(Na. Ca. Mg. K) silicates} + H_2CO_3 = H_4SiO^4 + HCO_3 + Na + Ca + Mg + K + \text{solid} \quad (1)$$

The groundwater of the prefecture of Ouham is not weakly mineralized (Fig. 1). The isotopic data for the samples from the north of the Central African Republic are close to Bangui's local meteoric water line and global meteoric water lines (Djebebe-ndjiguim et al., 2017), which does not indicate a strong influence of the evaporation (Fig. 2).

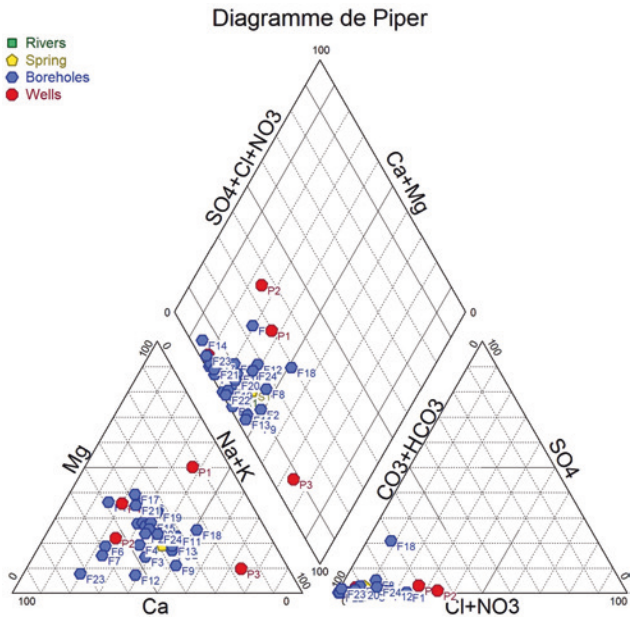

Fig. 1 Piper diagram for the water samples

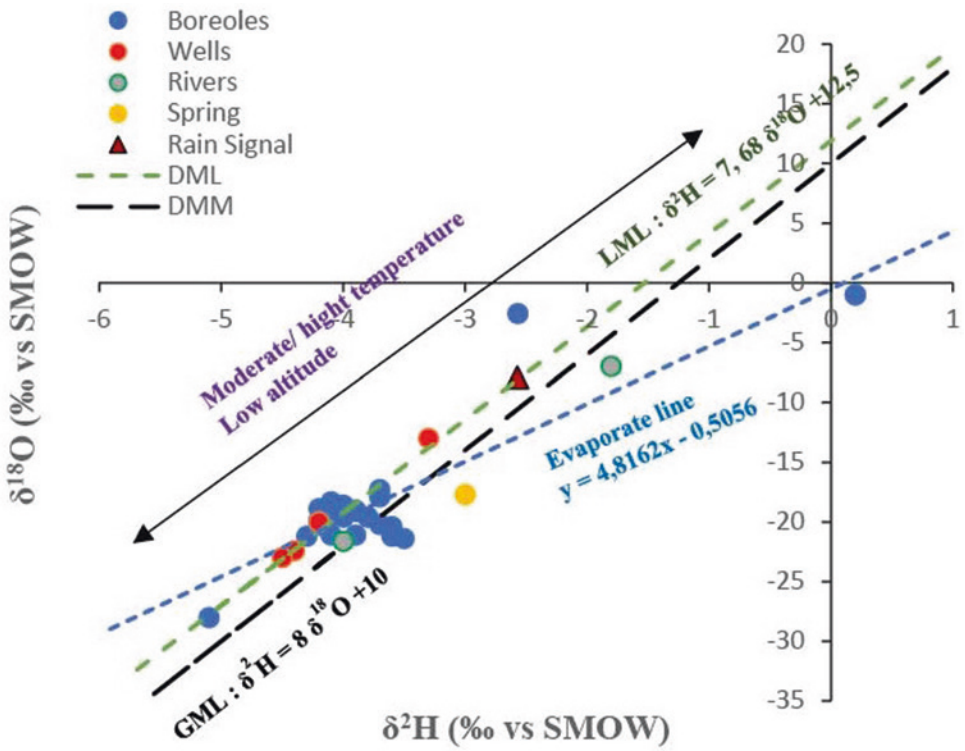

Fig. 2 Origin and mode of supply of water

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