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A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

The effects of the flood of October 2008 on the water quality in the M'zab valley, Algeria

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Abstract

With a flow estimated at 1200 $m^3 \cdot s^{-1}$ and a height of 8 m downstream, the flood that occurred on October 10, 2008 spread along the M'zab River over a length of more than 180 km. Material and human damage is visible, but its effects on the quality of the waters of the alluvial layer remain unknown: this is the purpose of this paper. Samples of groundwater were taken during the period 2005–2012 in 4 oases of the valley. Physicochemical analyses were performed using molecular and flame spectroscopic methods and also volumetric methods on water samples. The results obtained were interpreted using histograms and hydrochemical diagrams, such as the Avignon software (L.H.A) (version 4, 2008). Low effect of flood on the water quality of the alluvial aquifer was manifested by concentrations of magnesium sulphate and calcium chloride. On the other hand, there is an accumulation of salts infiltrated by sewage except for the zone of Bouchen. The diagrams show that there is an improvement in water quality in this area.

Key words: *flood of 2008, groundwater, histogram, hydrochemical diagram, hydrochemistry, M'zab valley, water quality*

INTRODUCTION

The scarcity of free surface flows are characteristic of dry areas, however flashes floods and of short duration may occur at any day of the year. The consequences of these floods are generally harmful; material and human damage can occur. It is for these reasons that torrential rains and their subsequent superficial runoff in the Sahara must be studied to provide better flood protection and water management plans [BADAWY 2016]. The M'zab valley, a hyper arid and rocky region well known by these devastating floods. However, floods are of great importance for the entire region of the M'zab valley. The arrival of a flood in the M'zab River represents a unique event, or all the families; old and young men and women leave their homes to go in front of the two banks of the wadi to observe the flow of the flood. A rocky region that favours surface runoff and consequently the inflow of the wadi is often quite high. The flood of the wadi of M'zab has a double advantage. Loaded with clay particles, the flood waters flood the palm groves thus allowing the plants to develop thanks to the nutritive elements carried by the floods. On the whole good to that observed in the M'zab valley, the flood is the only source of water which recharges the water table which is the only reservoir of fresh water of the region. To take advantage of the floods, the Mozabites have invented an ingenious ancestral system of sharing floodwaters for more than seven centuries [OUALED BELKHIR, REMINI 2016; REMINI *et al.* 2012]. Today, after the discovery of the Albian aquifer of the Intercalary Continental and the contribution of the boreholes in the valley of M'zab caused rise of the waters of the water table in several places of the valley of M'zab. Such a phenomenon much like that observed during the ninety years in the Souf valley [MILOUDI, REMINI 2016; 2018; REMINI 2004; 2006; REMINI, KECHAD 2011]. Mixed with wastewater discharges, these stagnant waters contaminate the groundwater. Then, the passage of a flood in the wadi of M'zab causes leaching in the wadi's bed and thus cleans up the waters. It is from this perspective that we examine the effects of the October 2008 floods on groundwater pollution. It should be noted that this flood recorded a flow exceeding 800 $m^3 \cdot s^{-1}$ [YAMANI *et al.* 2016].

STUDY AREA, MATERIALS AND METHODS

LOCATION AND CHARACTERISTICS OF THE STUDY AREA

The wilaya of Ghardaia is located in the northern part of the Algerian Sahara at 600 km south of the capital Algiers. With an area of more than 86 105 km^2, it is bordered on the North by the wilayas of Laghouat and Djelfa, on the East by the wilaya of Ouargla, on the West by the wilayas of Adrar and El Bayadh, to the South by the wilaya of Tamanrasset (Fig. 1). The M'zab valley has a large network of wadis, the main ones being Sebseb wadi, Metlili wadi, M'zab wadi, N'sa wadi and Zegrir River (Photo 1). All these rivers constitute the watershed of the M'zab valley. They drain most of the water from the western ridge to the East; their flow is sporadic and occurs as a result of thunderstorms in the region (Fig. 2). The climate of the valley is Saharan, characterized by hot summers and mild winters, especially during the day. The temperature is marked by large amplitude between day and night, summer and winter temperatures. The hot period starts in May and lasts until the month of September. The lowest average temperatures are recorded in January, 12°C and the highest in July, 40°C. The M'zab River extends over a length of 320 km and flows from West to East, from the region of El-Botma Rouila to 745 m a.s.l. where it is called Labiodh River; it empties into its

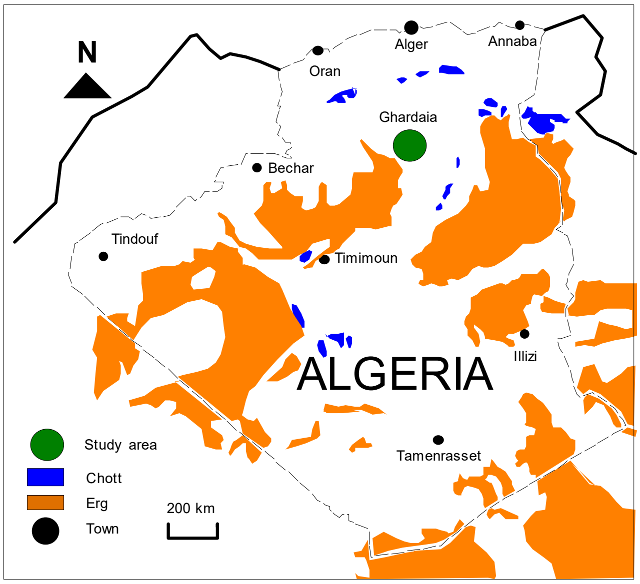

Fig. 1. Location of the study area (M'zab valley); source: own elaboration

Photo 1. A general view of the M'zab valley (phot. *B. Remini*)

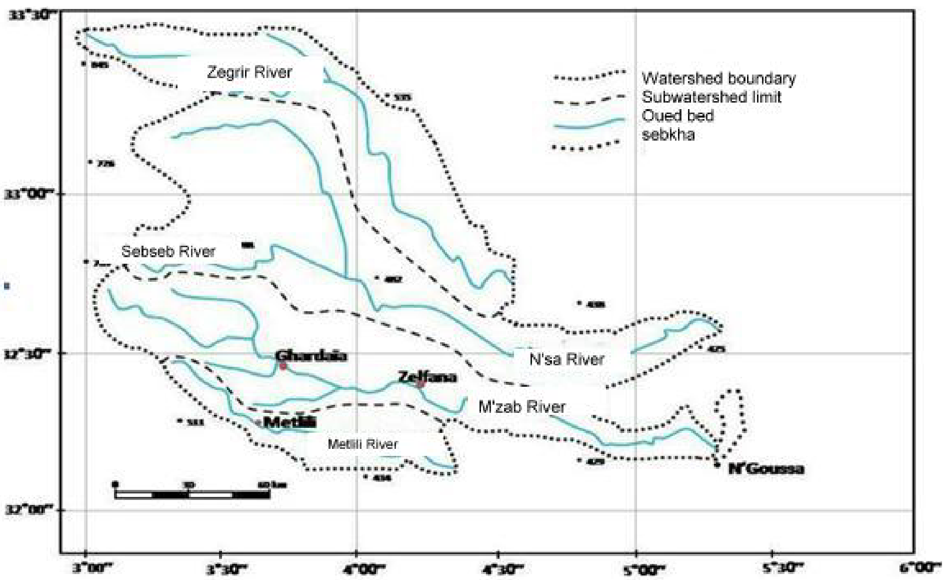

Fig. 2. Watershed of the M'zab region; source: ANRH [2007], extract from the map of DUBIEF [1953]

natural outlet which is the Sebkha of Safioune North of the city of Ouargla at an altitude of 107 m. The main tributary of M'zab River, called Labiodh wadi is located upstream of Ghardaia [ANRH 2007. The study area is characterized by a strong index of vulnerability due to the alluvial composition of medium and coarse permeable sand and also to the shallow depth of the aquifer [ACHOUR 2014]. The main aquifers in the M'zab valley are:

- **The alluvial aquifer (water table)**

The depth of the aquifer varies according to the topography; it varies between 5 and 30 m and increases towards the South-East. The alluvial aquifer contains the water table, which is a shallow water table, with a broad band North-South extension occupying most of the northern part of the Chebka [BNEDER 1988].

- **The aquifer of Intercalary Continental**

The Northern Sahara Aquifer System (SAS) extends over a large area with boundaries in Algeria, Tunisia and Libya. This basin contains a series of aquifers that have been grouped into two reservoirs called the Intercalary Continental (IC) and the Terminal Complex (TC). The Intercalary Continental aquifer generally drains the sandstone and sandstone-clay formations of Barremian and Albian. It is exploited, depending on the region, at a depth of 250 to 1000 m locally; the flow of water is from West to East.

SAMPLING AND HYDROCHEMICAL ANALYSIS

The choice of study area and sampling was based on representative wells located along the valley from upstream to downstream. The analysis points represented in this study are repetitive points for the four periods studied (Fig. 3). The analysis of the selected water samples, will allow us to try to explain the behaviour, the origin and the evolution of the chemical elements described and to evolve the degree of influence of the flood of October 2008 on the quality of these waters. The study is mainly based on sampling information from 20 water points, distributed in the field and over four periods, between 2005 and 2012 (2005, 2006, 2010 and 2012).

STUDY METHODS

The parameters studied in this work are the potential of hydrogen (pH), electrical conductivity (*EC*), the hydrotimetric degree (*TH*) and the major elements of mineralization that determines the chemical facies of water and nitrates. The sampling points were distributed along the valley and the same parameters are redone over four periods before and after the flood in order to see if there is a change in the salinity parameters of the water table. To interpret this work, we used hydrochemical software from Avignon (L.H.A version 2008) and histograms. We conducted an analysis of the major elements: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-} and NO_3^{-}.

The analyses were carried out in the central laboratory of the Algerian of the Wilaya of Ghardaïa.

pH and electrical conductivity are analysed using electrochemical devices;

- calcium, magnesium, hydrotimetric title, chloride, total alkalinity are all analysed by the volumetric method;
- sodium and potassium are analysed by flame spectrophotometry;
- nitrates are analysed by the molecular absorption spectrophotometry method;
- sulphates (SO_4) and dry residue are analysed by the gravimetric method.

RESULTS AND DISCUSSION

PHYSICOCHEMICAL PARAMETERS

pH. It is a parameter that determines acidity or alkalinity. For the year 2005 we obtained a maximum of 7.08 and a minimum of 6.65. For the year 2006, we obtained a pH between 7.08 (min) and 7.97 (max). For the year 2010, we obtained a pH which varies between 6.88 (min) and 8.34 (max). In the year 2012, we obtained a pH which varies between 6.9 (min) and 8.22 (max). These values show that well water is within the potability range (6.5–8.5) (Fig. 4). There is a tendency towards an increase of the pH, so an alkaline water.

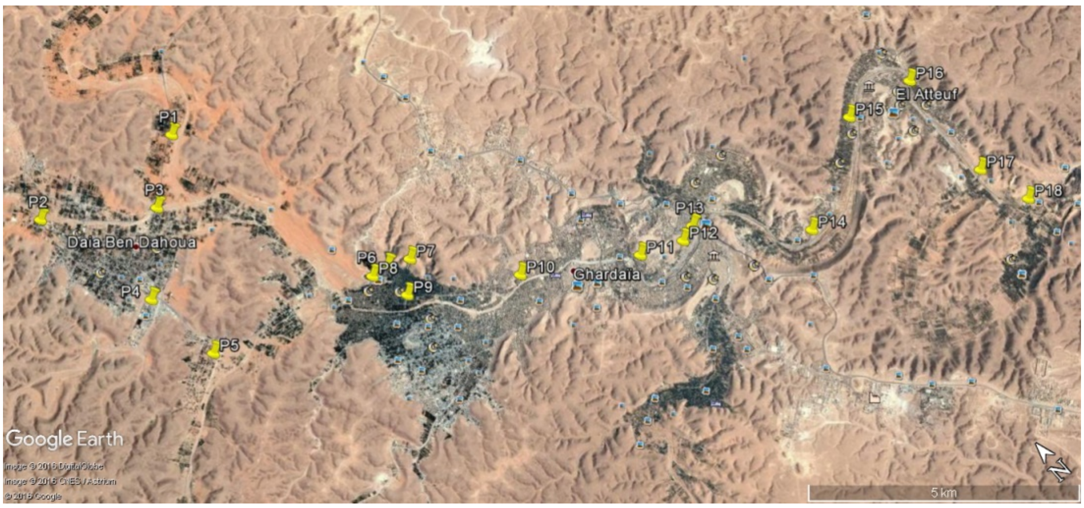

Fig. 3. Sampling points along the M'zab Valley; source: own elaboration based on Google Earth map

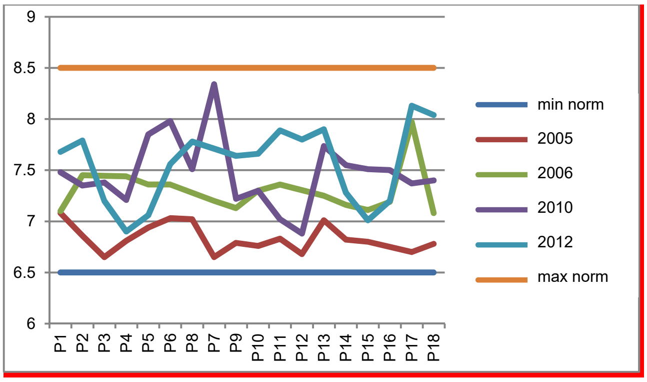

Fig. 4. Spatial and temporal variation of pH;
P1–P18 = measurement points as in Fig. 3; source: own study

Electrical conductivity (*EC*). In the year 2005, we have a maximum of 6 980 and a minimum of 547. For the year 2006, we obtained a minimum of 1 707 (P1) and a maximum of 8 000 (P17). In the year 2010, we recorded a minimum of 491 and a maximum of 8 750. In the year 2012, we obtained a minimum of 1 360 and a maximum of 6 619. The values of electrical conductivity show that most wells exceed the recommended standard for water potability (2 600 $\mu S \cdot cm^{-1}$). The minimum values of the order of 491 to 1 360 $\mu S \cdot cm^{-1}$ are recorded upstream of the water table in the Bouchen area. The maximum values exceed 8 000 $\mu S \cdot cm^{-1}$. Conductivity begins with low values upstream of the valley and then increases to P5. Conductivity decreases at point P7 and point P8 in the Bouchen area. Conductivity resumes its increase downstream of the valley (Fig. 5).

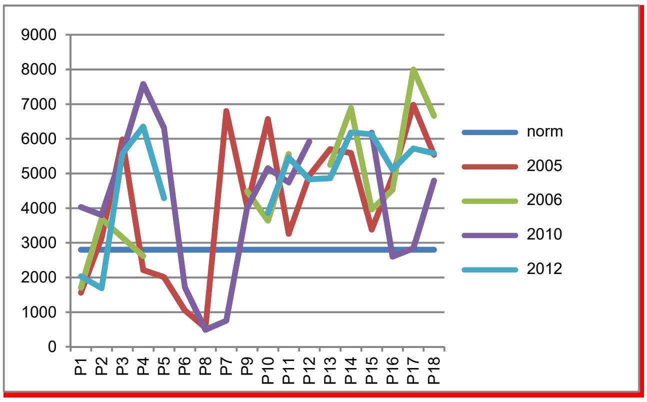

Fig. 5. Spatial and temporal variation of electrical conductivity (*EC*); P1–P18 = measurement points as in Fig. 3; source: own study

Diagram of Piper. The Figure 6 showing the hydrochemical facies of the four study periods (before and after the 2008 flood) shows that there is not a significant variation in the facies of the waters studied. The chemistry of the waters analysed is characterized by chlorinated, calcic and magnesium sulphated facies. In the year 2005, the majority of the analysed points present a chloric and sulphated facies calcium and magnesium. There is 98% dominant cation apart from the well P8 (Bouchen) which migrates to the bicarbonate zone. In the year 2006, the waters are chlorinated and sulphated calcium and magnesium. There is no dominant cation. In the year 2010, water keeps the same facies, 94% no dominant cation. The Bouchen wells converge towards the calcium zone. For the anionic composition, it is sulphated, chlorinated (28% sulphated 28% no dominant anion 42% chlorinated). Globally the waters have a chlorinated, sulphated, calcic and magnesium facies. In the year 2012, the waters have a sulphated facies chlorinated, calcic and Magnesian except the point P8 (Bouchen) which leaves towards the calcium side. The point P18 which has just made a migration for the year 2012 to the sodium chloride zone. This migration is due to the excessive concentration of sodium downstream of the valley.

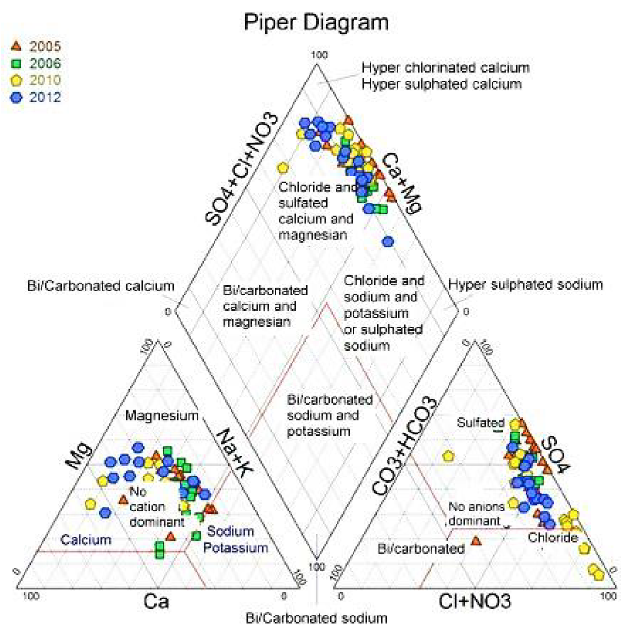

Fig. 6. Piper diagram; source: own study

CLASSIFICATION OF ANALYZED WATERS ACCORDING TO SCHOLLER AND BERKALOFF

The Figure 7a–d shows the Scholler and Berkaloff diagram for the four periods. In the year 2005, all the points have the same composition except P1, P6 and P8 (Fig. 7a). The point P1 is the upstream of the Labiod River valley. Points P6 and P8 are in the Bouchen area. In the year 2006 we see in Figure 7b, that all the wells have the same quality, except the points: P1and P2 have a slightly weak magnesium concentration. In the year 2010, all the waters of the wells have the same chemical facies, except the water at bridge P5 which leaves the group and takes another quality (Fig. 7c). In 2012, the water from the wells kept the same pace, except the water from the Bouchen wells upstream of the valley which has a less concentrated facies.

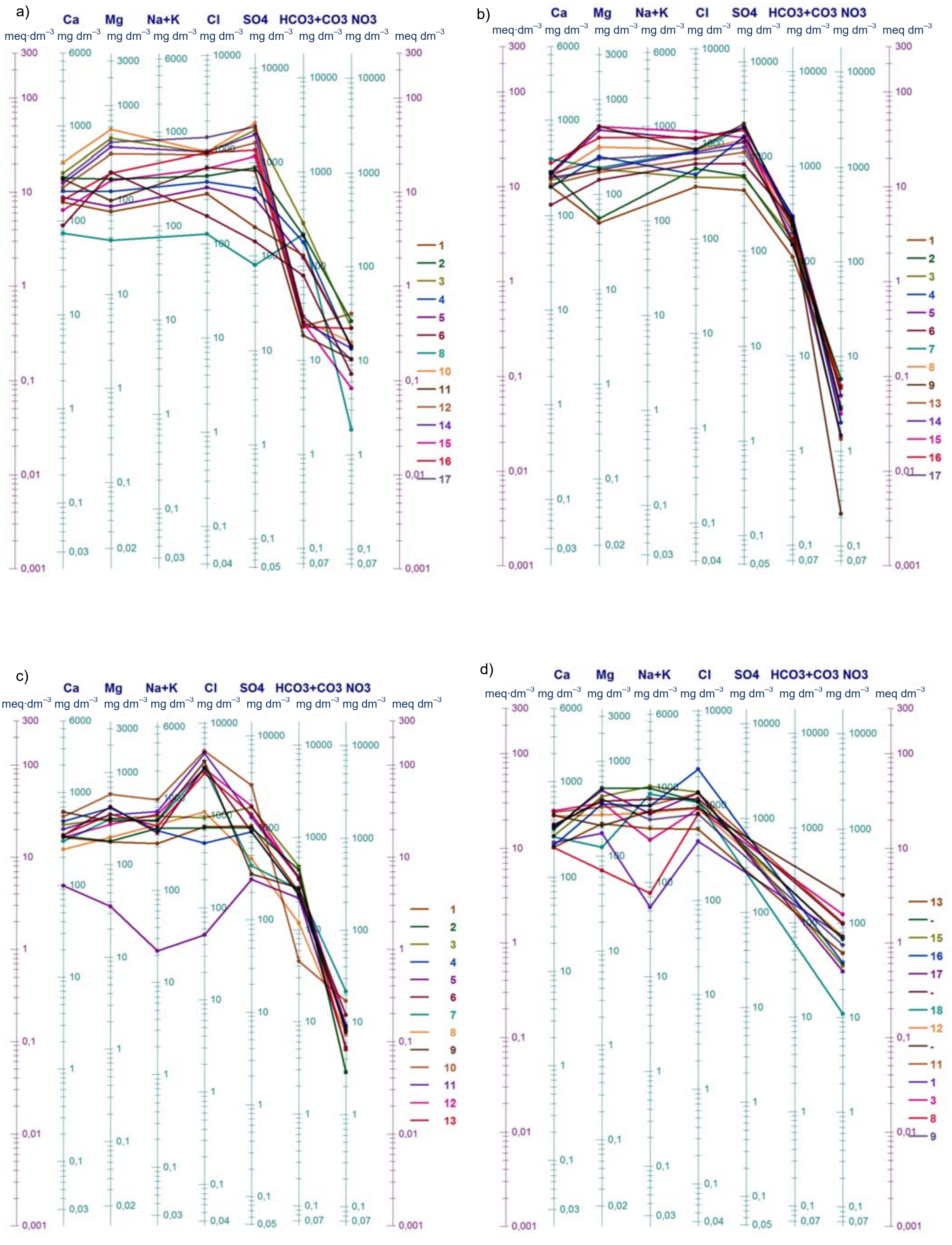

Fig. 7. Diagram of Scholler and Berkaloff: a) year 2005, b) year 2006, c) year 2010, d) year 2012, P1–P18 = measurement points as in Fig. 3; source: own study

WATER CLASSIFICATION ACCORDING TO THE STABELER DIAGRAM

The Stabeler diagram gives the cationic and anionic ratio of the elements in reaction. In the year 2005, from the upstream to the downstream, the calcium composition decreases and becomes sodium (Fig. 8a). In the year 2006, the Stabeler diagram for well waters has a magnesium calcium chloride sulphated facies (Fig. 8b). In the year 2010, the waters of the wells show the diagram of the carbonated composition is clear for P2, P7 and P8 (Fig. 8c). In the year 2012, the Stabeler diagram for well waters shows a magnesium calcium chloride and sodium chloride facies for some wells (Fig. 8d).

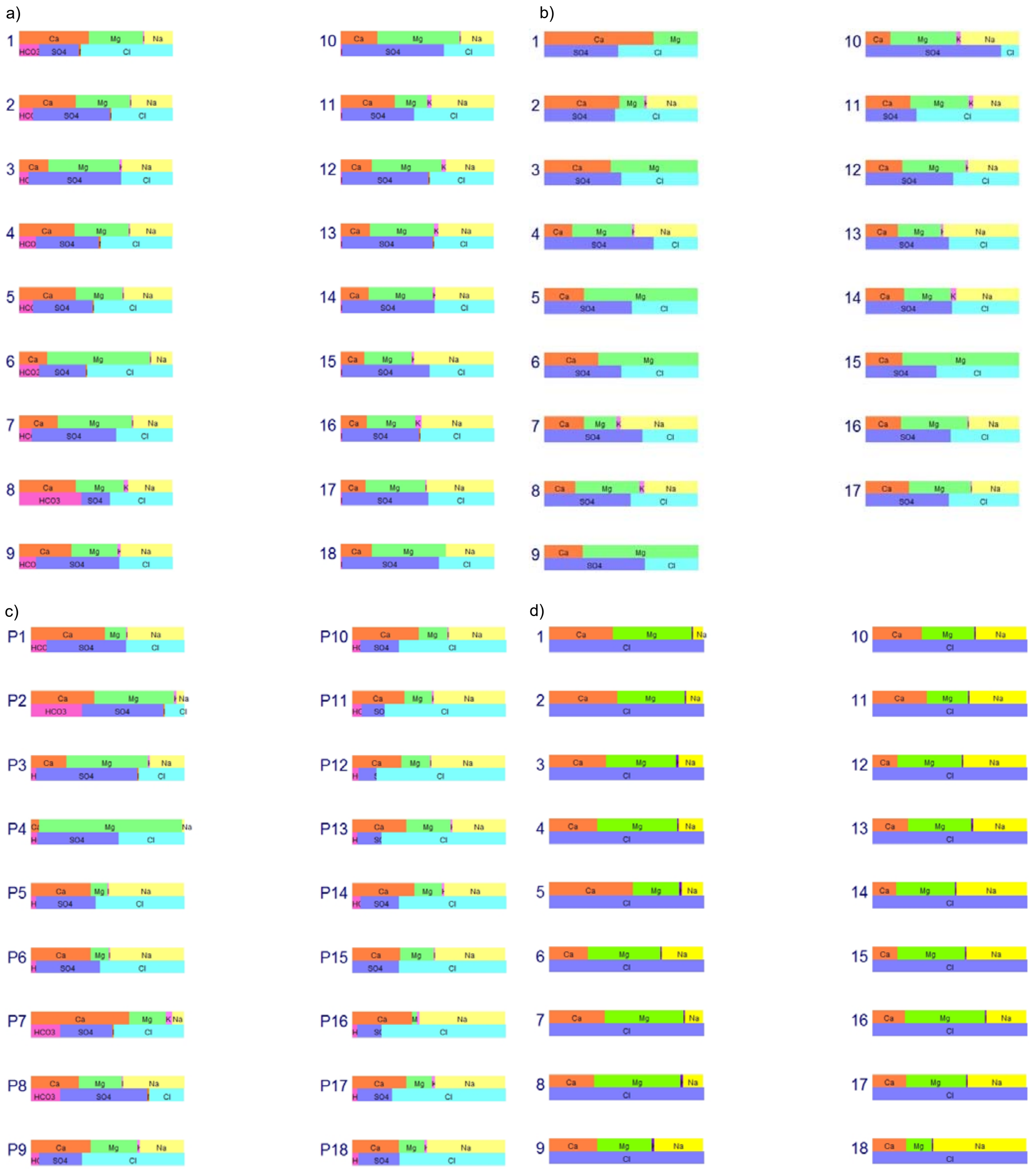

Fig. 8. Stabeler diagram of well water in analysed years: a) 2005, b) 2006, c) 2010, d) 2012; P1–P8 = measurement points as in Fig. 3; own study

VARIATION OF BOD_5 AND COD IN THE VALLEY

Figure 9 shows the variation of the COD (chemical oxygen demand) which corresponds to an estimation of the oxidizable materials presented in the water regardless of their organic or mineral origin. The same figure also represents the BOD_5 (biochemical oxygen demand) which gives an indication of the bacterial activity for the year 2005. The values obtained for the year 2005 show an increase of the BOD_5 upstream. It is due to the lack of sanitation network. Downstream is the wastewater outlet. For COD values are low with a small increase at point P11 (large agglomeration area). It is probable due to releases of household detergents.

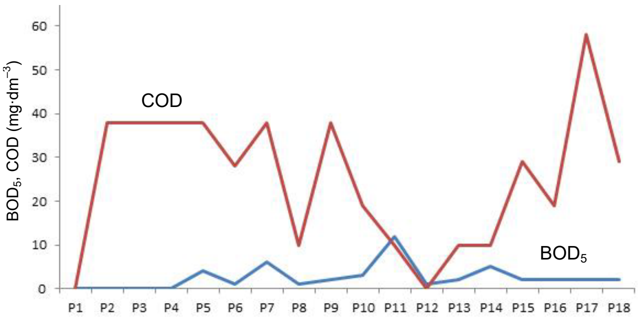

Fig. 9. Variation of BOD_5 and COD in the M'zab valley; P1–P18 = measurement points as in Fig. 3; source: own study

CONCLUSIONS

The waters of the superficial aquifer of the so-called Quaternary alluvial M'zab valley (groundwater) are of a magnesium sulphate calcium chloride facies. Upstream of the valley, the waters of the superficial aquifer are of low salinity and are in the standards of potability. In the town of Daia, the concentrations of major elements of mineralization reach peaks in the histograms. This situation is due to the lack of sanitation network. Sewage seepage into the water table is frequent. The area of Bouchen (upstream of the valley) after Daia is a special case especially for the last two years (2010 and 2012). This area retains good water quality (see Scholler-Berkaloff and Piper diagrams). The Bouchen area has a layer separated from the water table; it is influenced by rainwater and floods. After the zone of Bouchen the salt concentrations increase according to the general direction of the flow of the sheet (from NW to SE). According to the Piper and Stabeler diagrams, there is a chemical facies migration from sulphated magnesium chloride and calcium chloride to sulphated sodium chloride. This phenomenon can be explained by the accumulation of wastewater infiltrated into the water table along the valley (lack of sanitation networks for a long time). So, there is no influence of the flood of 2008 on the quality of the waters of the water table (on the contrary there is an accumulation of the salts infiltrating by the sewage) apart from the zone of Bouchen where its facies that was sulphated calcium chloride and magnesium for 2005 and 2006 migrates to the magnesia calcic bicarbonate facies.

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Wpływ powodzi z października 2008 roku na jakość wody w dolinie M'zab, Algieria

STRESZCZENIE

Osiągając przepływ szacowany na 1200 $m^3 \cdot s^{-1}$ i wysokość fali 8 m, powódź, która wystąpiła 10 października 2008 r., objęła swoim zasięgiem 180 km biegu rzeki M'zab. Straty ludzkie i materialne są znane, ale wpływ powodzi na jakość wody poziomów aluwialnych pozostaje nierozpoznany i dlatego stał się celem niniejszych badań. Próbki wód gruntowych pobierano w latach 2005–2012 w czterech oazach w dolinie rzeki. Próbki zostały poddane analizom fizycznym i chemicznym. Otrzymane wyniki interpretowano z wykorzystaniem histogramów i diagramów hydrochemicznych opracowanych za pomocą oprogramowania Avignon (L.H.A), wersja 4, 2008. Stężenie siarczanu magnezu i chlorku wapnia dowodziło niewielkiego wpływu powodzi na jakość wód aluwialnych poziomów wodonośnych. Z wyjątkiem strefy Bouchen, stwierdzono jednak akumulację soli infiltrujących ze ściekami. Na podstawie wyników badań można zaobserwować poprawę jakości wody na badanym obszarze.

Słowa kluczowe: *diagram hydrochemiczny, dolina M'zab, histogram, hydrochemia, jakość wody, powódź 2008, wody podziemne*