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Research Paper

Impact of the September 2018 floods on the quality of the Grombalia groundwater

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Abstract. The objective of this work is to study the effect of floods on the quality of the groundwater aquifer of the Grombalia region in September 2018. The study established salinity maps and addressed the salinity section to reach this purpose. This approach made it possible to draw curves of the salinity evolution over the entire groundwater surface. The salinity map of the year 2019 which describes the state of the groundwater of Grombalia following the significant flooding in September 2018, shows a remarkable improvement in the quality of the groundwater in all areas of the groundwater compared to previous periods. On the other hand, the salinity has decreased enormously; it varies from 0.32 to 2.8 g/L. The approach of the salinity sections revealed a variety of origins of the salinization of the groundwater. However, they show a close similarity with the shape of the piezometric sections of the groundwater. All the sections that pass through the flood zones illustrate a significant decrease in salinity in May 2019. The salinity does not exceed 2 g/L, even in Sebkhat Melah and irrigated areas. In conclusion, floods have a very positive impact on the water quality of the groundwater aquifer and are the most impactful factor in the variation of the salinity of the groundwater of Grombalia.

Keywords: Plain of Grombalia, groundwater, floods, salinity map, salinity section.

INTRODUCTION

The plain of Grombalia is a coastal plain located in the North East of Tunisia (Figure 1). It is the swallowing zone of the Wadi El Bey watershed. This plain covers an area of 411 km² (El Heni, 2007). The Grombalia Plain is a major collapse ditch associated with basement subsidence of more than 500 m filled with very thick quaternary deposits (Castany, 1948). This plain consists of three water tables: groundwater (363 km²) a semi-deep water table and a deep water table (Ennabli, 1980). The Grombalia groundwater which is the subject of this work is submitted to intensive exploitation for irrigation purposes.

In September 2018, the Grombalia plain experienced significant flooding. The objective of this work is to study the effect of the floods of September 2018 on the quality of the groundwater aquifer of the Grombalia region. To reach this purpose, salinity maps have been established and the salinity section was addressed. This approach made it possible to draw curves of the salinity evolution over the entire groundwater surface. The approach taken in this work attempts to:

- describe the methodology and tools of the work.
- study the spatial evolution of the salinity of the Grombalia groundwater to diagnose the effect of the September 2018 floods on the salinity of the groundwater.

MATERIALS AND METHODS

To better analyze the effect of hydraulic structures and the

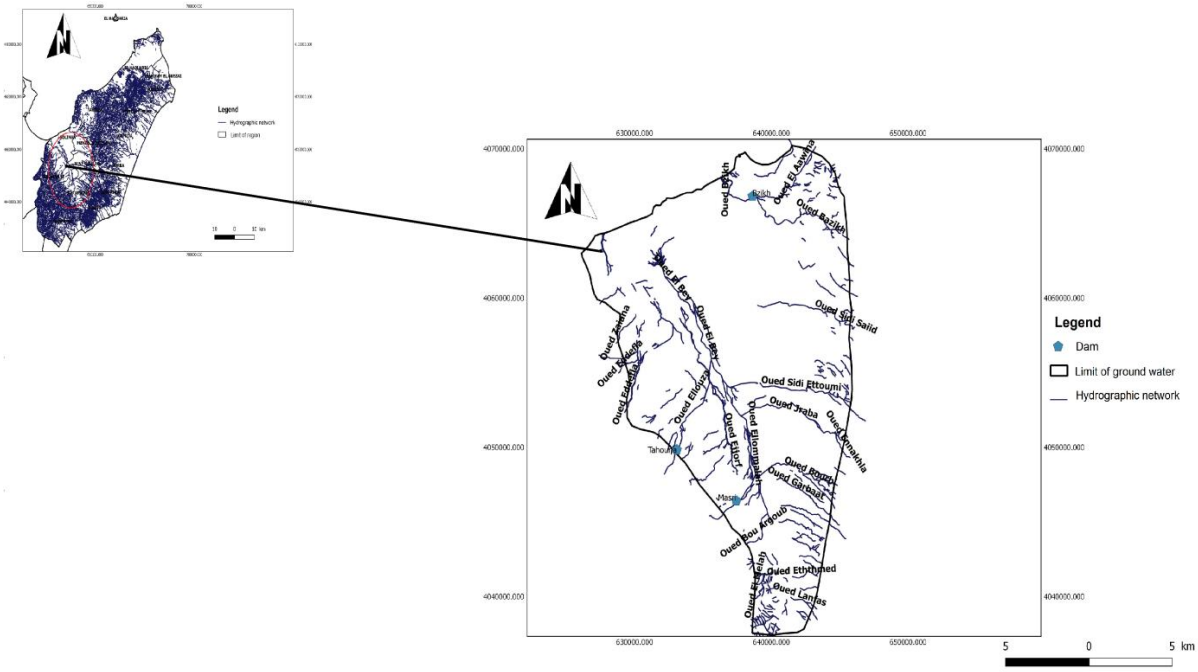


Figure 1. Study area.

September 2018 floods on the quality of the groundwater, the study established:

- seven salinity maps using the QGIS software and based on the surveillance network of the Grombalia groundwater. These salinity maps correspond to the periods: May 1997, May 2000, May 2005, May 2009, May 2015, May 2017 and May 2019.
-salinity sections, this approach make it possible to draw curves of changes in salinity over the entire groundwater surface. This involves making sections to the corresponding Raster layers in May 1997, May 2000, May 2005, May 2009, May 2015, May 2017 and May 2019. Indeed the study took seven sections: cc', dd', jj', kk', rr', qq' and ss' and it followed the salinity state for each section using the distance between the lowest point (starting point) and the highest (end) as a function of the salinity level saved for each distance.

In this work, the study will present only 5 salinity maps in May 1997, May 2000, May 2005, May 2009, and May 2019 and four salinity sections, which are cc', kk, rr' and ss'.

RESULTS AND DISCUSSION

Salinity maps

Many natural factors contribute to water quality such as: a) the groundwaters recharge source and its chemical composition, (b) the litho-logical and hydrological characteristics of the aquifer, and (c) the rate of groundwater turnover.

To better control the effect of these three factors on groundwater quality, seven salinity maps have been drawn for the highest water periods: May 1997, May 2000, May 2005, May 2009, May 2015, May 2017 and May 2019.

May-1997 salinity map

The salinity map of the year 1997 shows that the salinity values are between 1.6 and 4.2 g/L. (DGRE, 1997**,** Annual book of the quality of groundwaters). In particular, two areas with high salinity were detected:

- An area to the north, near the coast just east of Sebkhat El Melah. These relatively high values can be explained by the contributions of saline waters of the Sebkhat (salt deposits) and/or the sea.
- An area in the southern part of the groundwater. The increase in salinity of the water is related to the infiltration of leaching water from very saline soils and to the use of fertilizers in agriculture. Excessive exploitation in these two areas also indirectly influences the rise in salinity. As you move away from these areas, the salinity decreases particularly going east, towards Menzel Bou Zelfa, Beni Khalled and Bou Argoub.

The saline load of the Grombalia groundwater is under the influence of:

- artificial recharge at Menzel Bou Zelfa and Beni Khalled (dilution effect).

- the nature of the permeability of the aquifer which is sandy and permeable in the East, clayey and relatively not very permeable in the West.

May 2000 salinity map

The salinity map for the year 2000 shows a significant increase in salinity at the scale of the aquifer, yet there is a decrease in exploitation. Indeed the salinity varies between 1.85 and 6.83 g/L. (DGRE, 2000**,** Annual book of the quality of groundwaters). This increase is marked especially near the coast just east of Sebkhat El Melah due to a marine intrusion and infiltration of the saline waters of Sebkhat El Melah. The presence of the two described areas persists in 2000 but with higher salinity values. There is also a remarkable increase in salinity in the Bou Argoub area near the Masri dam.

May-2005 salinity map

This map describes the state of the groundwater after the completion of the last recharge site at Bou Argoub and after two wet years (2003 and 2004 (1000 mm) (DGRE, 2003 and 2004, Annual book of rainfall), where there is a renewal and dilution of the groundwater. As a result groundwater use decreased by 4 million cubic meters from 2000. This is why there has been a remarkable decrease in salinity at the groundwater level compared to the year 2000. Indeed, salinity varies between 0.8 and 6 g/L (DGRE, 2000**,** Annual book of the quality of groundwaters).

May-2009 salinity map

The salinity map for the year 2009 shows a significant increase in the salinity at the groundwater scale, which is due to an increase in the exploitation and increased fertilizer use in agriculture. Indeed the salinity varies between 1 and 6.2 g/L (DGRE, 2009, Annual book of the quality of groundwaters), and the studies still have the same distribution of the two zones, but the variation exists in the measured salinity values.

May-2019 salinity map

The salinity map for the year 2019 shows a remarkable improvement in the quality of the groundwater. Indeed the salinity has greatly decreased; but it varies from 0.32 to 2.8 g/L (DGRE, 2019**,** Annual book of the quality of groundwaters), which is due to the floods of September 2018 (Figure 2). Indeed, it is noted that where the flood exists, the light beige colors illustrate the flood zones well. In the nature and the permeability of the aquifer which is sandy and permeable in the East, clayey and relatively low permeable in the West can influence the rate of renewal of the groundwater and consequently influence the saline load, and this is why the highest values of salinity are found to the West of the plain.

Localisation of salinity section

The selected sections are cc', kk', rr' and ss' (Figure 3). These sections are all different; made in different directions, and each one illustrates in detail the effect of the different structures on salinity.

Salinity section cc'

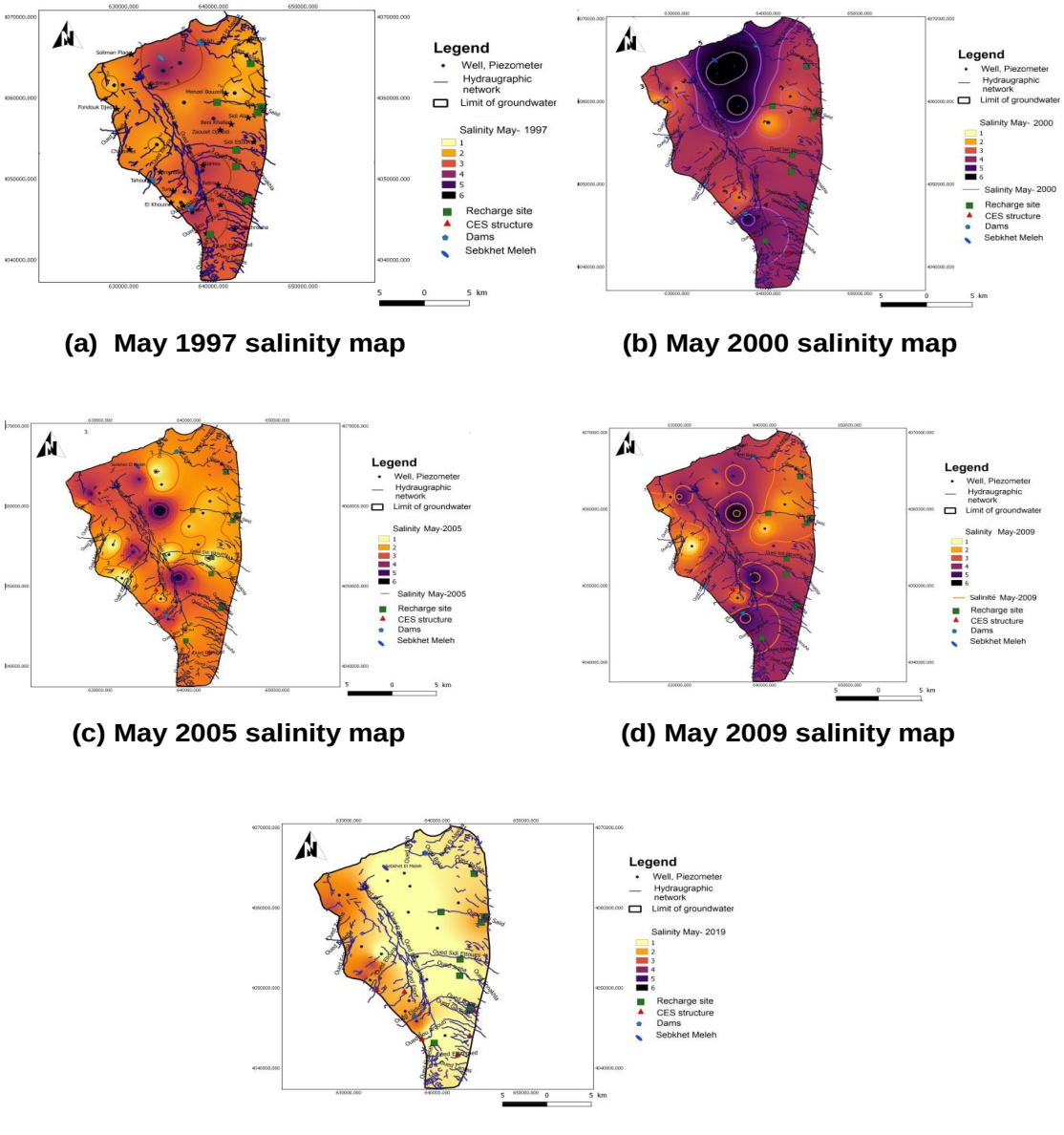
The cc' section begins with the point x=0, which is the level closest to the coast and crosses Wadi Bazikh and ends at Wadi Ennakhla at the southeast end of the groundwater. Its length is about 21 km. First, this section crosses Oued Bazikh, and passes through the flooded area near the Bazikh dam. Next, it passes through Sebkhet el Melah then crosses the coastal cordon at about 5.5 km, then crosses the El Amrine recharge site at about 11 km. Next, it passes through the flooded area of Beni Khaled-Zaouiet Ejdid-Sidi Alaya, which is also an irrigated area. Next, it crosses Wadi Sidi Toumi at 15.5 km, passes through the flooded area of Sidi Toumi, and finally crosses the Gobba1 recharge site at about 16 km.

Salinity section kk'

The kk' section begins with the x = 0 point at CES Bou Argoub, which is the southwestern limit of the groundwater and ends at wadi Machrouha at the south-eastern extremity. Its length is approximately 23 km, and it crosses the Bou Argoub zone, and then passes through wadi Bou Argoub, then it crosses the Machrouha area and finally crosses wadi El Machrouha.

Salinity section rr'

The rr' section begins with the point x=0 at the wadi Ellouze near the Tahouna dam which is the south-western groundwater limit and ends at the Sidi Alaya recharge site level. Its length is about 19 km, it passes through wadi Ellouze near the Tahouna dam, then it passes through the flooded area of Grombalia-Turki which is an irrigated and overexploited area, then it crosses wadi Ejorf, then it crosses wadi Elommaleh, then it passes through wadi Bou Argoub, then it crosses the flooded area of Bou Argoub, which is an irrigated and overexploited area and finally it



(a) May 1997 salinity map

(b) May 2000 salinity map

(c) May 2005 salinity map

(d) May 2009 salinity map

(e) May 2019 salinity map

Figure 2. Salinity maps (May 1997, May 2000, May 2005, May 2009, and May 2019).

passes through the flooded Machrouha area which is an irrigated and overexploited area.

Salinity section ss'

The ss' section begins with the point x=0, which is the level closest to the coast and crosses wadi El- Bey and ends at the level of a tributary of wadi Sidi Said at the northeastern extremity of the groundwater. Its length is about 19 km, it passes through the flooded area of Soliman which is an overexploited area, then it crosses wadi El Bey, then it crosses the irrigated area of Menzel Bou Zelfa, then it passes through wadi Sidi Saïd and finally it crosses the flooded area of Sidi Alaya, which is an irrigated area.

Interpretation of salinity sections

Salinity section cc'

Figure 4a shows:

- A plateau all along the section where there is a flood

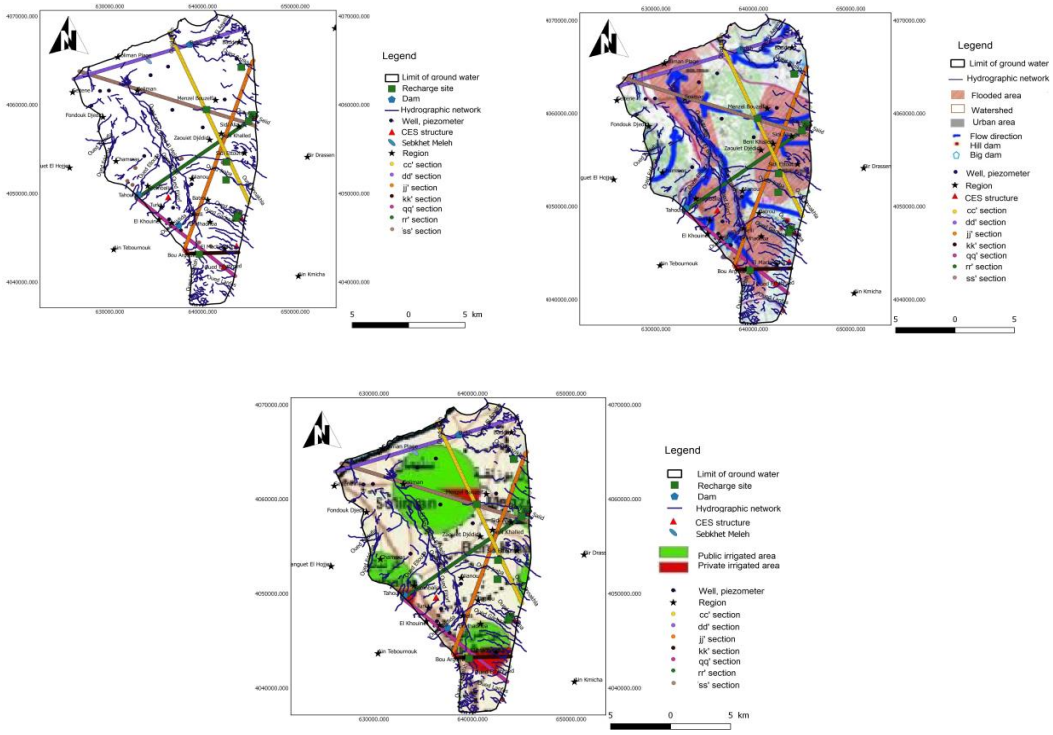


Figure 3. Localization maps of the salinity sections.

marked by the salinity curve May-2019 where the salinity is low and almost constant, it is between 0.8 and 1.1 g/L, which is due to the flood of September 2018 where there is a renewal and dilution of the groundwater.
- A convexity in the Soliman area near the coast is marked by salinity curves of May-1997, May-2000 and May-2009, due to marine intrusion. This convexity is attenuated in May-2005, May-2017, and May-2019.
- The first spike at Sebkhat el Melah was marked by the salinity curves of May_1997, May_2000 and May-2009, due to the infiltration of the saline waters of Sebkhat El Melah.
- A second spike at the coastal cord marked by the salinity curves May-2009, May-2015 and May-2017, where the accumulated water evaporated and the saline load increased.
-A first depression at the artificial recharge site El Amrine at about 11 km, due to the renewal and dilution of the groundwater by the injected water (DGRE (1997, 2000, 2005, 2009), Annual books of artificial recharge).
- A second depression at the wadi Sidi Toumi where there is a renewal and dilution of the groundwater by the contributions of the wadi.

Salinity section kk'

Figure 4b shows:

- a first depression marked by the May-2005 and May-2019 salinity curves at wadi Bou Argoub which feeds the aquifer from which the water in the aquifer is renewed and diluted. This depression was alleviated in May-1997, May-2000, May-2009, May-2015 and May-2017.
- a second depression marked by the May-2015 salinity curve at wadi Machrouha, which feeds the aquifer from which the aquifer water is renewed and diluted.

Salinity section rr'

Figure 4c shows:

- the first plateau is marked by all salinity curves at the level of the overexploited area of Grombalia; it is an irrigated area and was flooded in September 2018, in this area the salinity exceeds 1.7 g/L.
- a convexity at wadi Ellomalah is marked by the May-1997, May-2000, May-2005 and May-2009 salinity curves. This wadi drains the aquifer which increases the saline charge.
- a slight depression at about 6400m in a tributary of wadi Sidi Toumi marked by the May-2005, May-2015 and May-2019 salinity curves; and this wadi feeds the aquifer from which the water in the aquifer is renewed and diluted.
- a second depression marked by the May-2019 salinity curve from the flooded area of Grombalia to the flooded

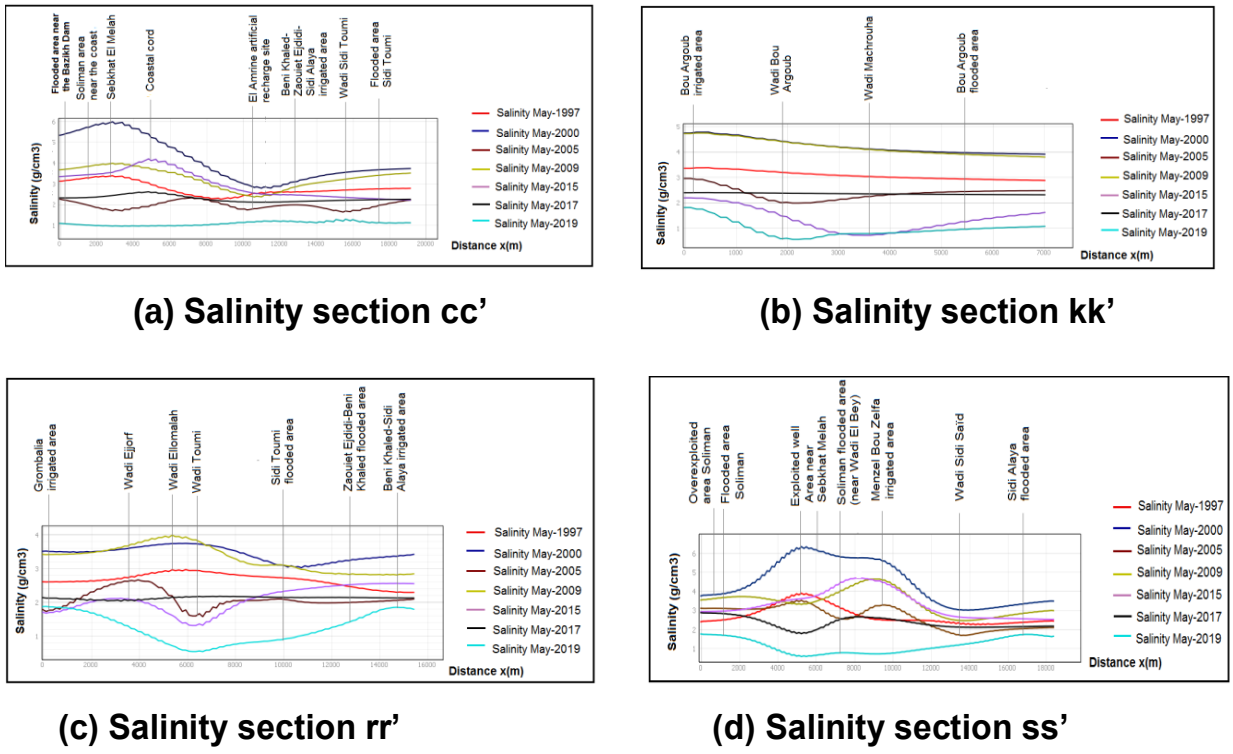


Figure 4. Salinity sections.

area of Béni Khaled Sidi Alaya.

Salinity section ss'

Figure 4d shows:

-A plateau all along the section where there is a flood marked by the May-2019 salinity curve where the salinity is low and almost constant, and it is between 0.5 and 1.6 g/L, which is due to the flood of September 2018 where there is a renewal and dilution of the groundwater.
- the first plateau marked by all the salinity curves at the level of the overexploited zone, an irrigated zone, where the salinity exceeded 4 g/L in 2000 and 3.5 g/L in 2009.
- a second plateau marked by the May-2000 salinity curve throughout the irrigated area from the Soliman area to the Menzel Bou Zelfa area.
- a first spike in an exploited area well marked by the salinity curves of May 1997 and May 2005.
- a second peak marked by the May-2005, May-2009 and May-2015 salinity curves at the level of the irrigated zone of Menzel Bou Zelfa which could be due to the intervention of surface infiltration water of irrigation, the local use of fertilizers and the intensive evaporation of the surface of irrigation water, which leads to the precipitation of salts.
- all marked salinity curves, and depression at Wadi Sidi Said.

CONCLUSION:

All salinity maps show that:

- highest salinity values are in irrigated areas and Sebkhat El Melah.
- the salinity decreases in particular by moving towards the East given the permeability of the aquifer which is sandy and permeable to the East. Clay and relatively low permeability in the West can influence the rate of renewal of the groundwater and consequently influence the saline load.

The salinity map for the year 2019, which describes the state of the Grombalia groundwater and the flooding marked in September 2018, shows a very remarkable improvement in the quality of the groundwater in all areas of the aquifer compared to previous periods. Indeed the salinity has greatly decreased, as it varies from 0.32 to 2.8 g/L.
The approach to the salinity section revealed a variety of origins of the salinization of groundwater. They show a rather narrow similarity with the shape of the piezometric sections of the groundwater. All the sections that cross the flood zones show a significant decrease in salinity in May 2019. The salinity does not exceed 2 g/L, even in Sebkhat Melah and in the irrigated zones. So floods have a very positive impact on the quality of the groundwater and come

in the first order in the change of the salinity of the groundwater of Grombalia.

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