Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
C. R. Geoscience 337 (2005) 515–524
COMPTES RENDUS GEOSCIENCE
http://france.elsevier.com/direct/CRAS2A/

Géosciences de surface (Hydrologie–Hydrogéologie)

Salinisation des nappes côtières : cas de la nappe nord du Sahel de Sfax, Tunisie

Rouaida Trabelsi, Moncef Zaïri *, Habib Smida, Hamed Ben Dhia

Laboratoire « Eau, Énergie et Environnement », École nationale d'ingénieurs de Sfax, BP W, 3038 Sfax, Tunisie

Reçu le 21 juin 2004 ; accepté après révision le 8 novembre 2004

Disponible sur Internet le 25 février 2005

Présenté par Ghislain de Marsily

Résumé

Les eaux souterraines connaissent une dégradation de leur qualité en relation avec l'augmentation de la demande résultant de l'accroissement démographique rapide, l'urbanisation accélérée, la diversification des activités économiques et agricoles et l'amélioration du niveau de vie des citoyens. Cette dégradation est généralement exprimée par la salinisation et la contamination de ces eaux. La détermination de l'origine de la salinité des eaux de la nappe phréatique nord du Sahel de Sfax a été approchée à partir de l'étude de l'évolution dans l'espace des éléments chimiques majeurs. L'interprétation des données d'analyse et la répartition des eaux souterraines en groupes homogènes sont réalisées en utilisant les diagrammes de Stiff, de Durov étendu, et d'éléments pris deux à deux. L'étude a révélé une variété d'origines et de processus de la salinisation des eaux souterraines. Ainsi, dans la partie amont, ce phénomène serait dû essentiellement à la dissolution/précipitation des minéraux de la formation réservoir (groupe I). L'effet du mouvement de retour des eaux d'irrigation et de pompage intensif est considéré comme étant la principale origine de la minéralisation des eaux des groupes II et III, caractérisées par des réactions d'échange ionique direct et de mélange. L'anomalie de forte salinité observée au niveau de la zone Hazeg est expliquée par une contamination de la nappe par les eaux de mer. Cette hypothèse d'intrusion marine est justifiée par les fortes teneurs en chlorures dues à la présence de réactions d'échange cationique inverse (groupe IV) et par une piézomètrie inférieure au niveau de la mer. ***Pour citer cet article : R. Trabelsi et al., C. R. Geoscience 337 (2005).***

Abstract

Salinization of coastal aquifers: case of the North Sfax Sahel aquifer, Tunisia. The intensive agricultural and economic activities induce the increase of the risk of groundwater quality degradation through high groundwater pumping rates. The salinization and contamination are the main sources of this pollution, especially in coastal aquifers. The explanation of the origin of salinity for the shallow aquifer of Northern Sahel of Sfax was analysed by a chemical study of the groundwater main compounds. The partitioning of groundwaters into homogenous groups is undertaken by graphical techniques, including a Stiff pattern diagram, an expanded Durov diagram and several binary diagrams. The study indicates the presence of various

* Auteur correspondant.
Adresse e-mail : moncef.zairi@enis.rnu.tn (M. Zaïri).

1631-0713/$ – see front matter © 2005 Académie des sciences. Publié par Elsevier SAS. Tous droits réservés.
doi:10.1016/j.crte.2005.01.010

salinization processes. In the recharge area, salinization is the result of dissolution/precipitation of the aquifer formation material (group I). The irrigation water return and the intensive pumping have been identified as major sources of salinization in the south by direct cation exchange and mixing reactions (groups II and III). The anomaly of high groundwater salinity observed near the Hazeg zone was explained by the presence of a seawater intrusion in this area. This hypothesis is related to the high chloride concentration, to the presence of inverse cation exchange reactions (group IV), and to the piezometric level inferior to sea level.
To cite this article: R. Trabelsi et al., C. R. Geoscience 337 (2005).

Mots-clés : Nappe côtière ; Hydrochimie ; Salinisation ; Intrusion marine ; Tunisie

Keywords: Coastal aquifer; Hydrochemistry; Salinization; Seawater intrusion; Tunisia

Abridged English version

The uncontrolled groundwater extraction causes modification of the natural flow system and induces lateral flow of seawater from the coast and causes the groundwater quality degradation [20].

This study concerns the coastal phreatic aquifer of the northern Sahel of Sfax at the Centre-East of Tunisia (Fig. 1). This region has an arid climate, with extreme temperatures and rainfall variations with an average annual temperature and rainfall of 20 °C and 230 mm, respectively. The groundwater quality variations result mainly from intensive exploitation, agricultural activities and the presence of highly soluble minerals in the aquifer material.

The main object of this study was to outline the principal geochemical characteristics of the aquifer and to determine the origins and the mechanisms governing its salinization.

The northern Sahel of Sfax aquifer is located in the Mio-Pliocene layer system formed by sand and silty clay [10,14]. The aquifer is recharged by direct infiltration and its higher limit is at Medasse Sidi Salah. The discharge limits coincide with the Mediterranean shore line and the Sebkhas of El Ghorra and El Jem. The groundwater flow is mainly toward the south-east and may be locally disturbed by piezometric depressions due to the intensive exploitation (Fig. 2).

The actual pumping well density is about 100 to 110 wells per square kilometre, whereas it was of 30 to 45 wells per square kilometre in the 1970s.

The diagram in Fig. 3 gives the variations of annual rainfall, annual well withdrawal and groundwater chloride concentration at the zone of Hazeg. It indicates a parallel increase of the last two parameters versus time, while the first parameter decreases. This fact may be explained by seawater intrusion related to intensive exploitation [15].

Representative groundwater samples were obtained from 68 pumping wells during year 2002. The electrical conductivity, temperature and pH were measured in situ and the chemical analyses concerned Na, Ca, Mg, HCO_3, Cl, SO_4, K, Mn, and NO_3. The measured physical and chemical parameters showed large spatial variations. The electrical conductivity varied between 1748 and 18 190 $\mu S\ cm^{-1}$ and the salinity between 0.7 and 13.6 $g\ l^{-1}$ (Fig. 4).

The Stiff pattern diagrams with the groundwater samples location are indicated in Fig. 5. The various diagram shapes indicate heterogeneous water chemistry [22]. Based on this representation, four groundwater quality groups are identified: group I, accounting for 41% of the samples, group II for 30%, group III for 21% and group IV for 7%. Group I is found mainly in the northern part of the zone, group II in the southern part and group IV in the coastal area. The expanded Durov diagram (Fig. 6) was used to identify processes and reaction paths such as mixing, ion exchange and dissolution affecting groundwater composition [12,16]. Box 1 in Fig. 6 is usually the place for low salinity recently infiltrated water in sand aquifers, boxes 2 and 3 represent ion-exchange waters where high values of Mg, H_{CO_3} and Na are exchanged for low values of Ca [5]. The major part of the samples from group I is affected by aquifer material dissolution. Box 5, where a part of groups I, II and III is present, is close to conservative mixing waters. Most samples in group II and III are in box 6, indicating that both mixing and ion exchange are responsible for their quality. A maximum increase in the salinity should produce water in box 9, however, the samples of group IV and five samples from groups II and III are in boxes 8 and 7, because mixing and reverse ion exchange affect their composition.