C. R. Geoscience 342 (2010) 60–74

Contents lists available at ScienceDirect

Comptes Rendus Geoscience

www.sciencedirect.com

Surface geosciences (Hydrology–Hydrogeology)

A thirty-year artificial recharge experiment in a coastal aquifer in an arid zone: The Teboulba aquifer system (Tunisian Sahel)

Une expérience trentenaire de recharge artificielle d'une nappe côtière en zone aride : le système aquifère de Teboulba (Sahel Tunisien)

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ARTICLE INFO

Article history:
Received 17 July 2007
Accepted after revision 17 September 2009
Available online 11 December 2009

Presented by Ghislain de Marsily

Keywords:
Artificial recharge
Coastal aquifer
Salinisation
Water resources
Teboulba
Tunisia

Mots clés :
Recharge artificielle
Nappe côtière
Salinisation
Ressources hydriques
Teboulba
Tunisie

ABSTRACT

With the increased demand for groundwater resulting from fast demographic growth, accelerated urbanization, economic and agricultural activity diversification, and the increase of *per capita* consumption, ground water resources, in particular in coastal regions, remain relatively low, compared to demand. The groundwater quality and piezometric variations result mainly from intensive exploitation, agricultural activities and the intrusion of seawater. This phenomenon is observed mostly in semi-arid areas, such as the oriental Sahel of Tunisia, where an apparent reduction in rainfall in recent years can be seen. Groundwater becomes overexploited especially as its natural recharge by rainwater does not succeed in maintaining the hydrologic balance. The imbalance between water demand and resources induces the degradation of the water quality. In such a case, the artificial recharge of water-table aquifers by water from dams is a credible alternative to improve the hydrodynamic and physicochemical conditions of the groundwater. Like most coastal aquifers, the Teboulba water-table aquifer is threatened by overexploitation for at least three decades. This threat appears by a considerable piezometric level drop and by water salinisation, due to seawater intrusion. Given this alarming situation, since 1971, artificial recharge through wells with surface water from a dam was tested in order to restore the water levels and to improve water quality. The piezometric and chemical surveys of the Teboulba aquifer permitted one to describe the temporal and spatial piezometric and geochemical conditions of the aquifer and to show the effect of the artificial recharge. Indeed, the artificial recharge undertaken since 1971 made the geochemical and piezometric conditions of the Teboulba aquifer improve. This example is a rare, well-documented case-study of the benefits of artificial recharge in a coastal aquifer, over the long term.

RÉSUMÉ

Suite à l'augmentation de la demande en eau, résultant de l'accroissement démographique, de l'urbanisation accélérée, de la diversification des activités économiques et agricoles, et de l'augmentation de la consommation individuelle, les ressources hydriques souterraines, en particulier dans les régions côtières, restent relativement faibles devant les besoins. Cela fait que les eaux souterraines deviennent de plus en plus sollicitées et

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1631-0713/$ – see front matter
doi:10.1016/j.crte.2009.10.008

surexploitées quand leur alimentation directe par les eaux de pluie n'arrive plus à rétablir un équilibre, parfois aussi compromis par des conditions climatiques difficiles et des sécheresses à répétition. Le déséquilibre entre une alimentation faible et une exploitation intense conduit alors à la dégradation de la qualité des eaux. Dans ce cas, la recharge artificielle des nappes phréatiques par les eaux des barrages constitue une alternative crédible pour améliorer les caractéristiques piézométriques et physicochimiques des eaux souterraines. Comme toutes les nappes littorales, la nappe de Teboulba (Sahel tunisien) se montre, depuis plus de trois décennies, très menacée par la sur-exploitation. Cette menace se manifeste par un abaissement considérable du niveau piézométrique provoquant le tarissement de certains puits et par la salinisation des eaux, due essentiellement à des intrusions d'eau salée. Depuis 1971, cette nappe a fait l'objet d'essais de recharge artificielle par les eaux du barrage de Nebhana, afin de restaurer son équilibre hydrodynamique et d'améliorer la qualité de ses eaux. Le suivi du niveau piézométrique et de la salinité des eaux de la nappe de Teboulba a permis de décrire l'évolution temporelle et spatiale des caractéristiques piézométriques et hydrochimiques de la nappe et de mettre en relief l'effet de la recharge artificielle. En effet, suite aux campagnes de recharge artificielle réalisées depuis 1971, la remontée piézométrique a été considérable et les eaux de la nappe de Teboulba sont devenues relativement moins chargées en sels. Ce cas constitue un exemple rare très documenté de l'effet bénéfique de la recharge artificielle sur une nappe côtière, sur une longue durée.

1. Introduction

Artificial recharge of aquifers is devised as a means to increase groundwater resources while regulating surface flow, providing underground storage of this water and avoiding its becoming lost in the sea or in salt depressions, or its evaporation in dams. A large number of water-table aquifers in coastal zones are being increasingly exploited and affected by a constantly growing human impact (Bouwer and Pyne, 2005; de Marsily, 2003; Fedrigoni et al., 2001; Kouzana et al., 2009). In fact, overexploitation of a coastal water-table aquifer can threaten the whole aquifer and deteriorate its hydrological and hydrochemical characteristics. Therefore, this technique can be used especially to preserve the water resources against marine intrusion and/or a pronounced fall in the piezometric level. Currently, the share of total withdrawn groundwater quantities attributed to overexploitation is considerable in several Mediterranean countries: 20% in Gaza, 32% in Israel, where the overexploitation is to a great extent compensated by artificial recharge (Aberbach and Sellinger, 1998), 8 to 10% in Tunisia, partially compensated by artificial recharge (Ministère de l'agriculture, Tunisia, 1996; Margat, 2004). The last is a pilot programme to mobilise resources; the aim is to store water from winter rains available in great quantity and to use it during the dry season (Asano and Cotruvo, 2004; Foster and Chilton, 2004). The objective here is to recreate, for the following year, a piezometric level that is higher than or equal to that of the previous year (Detay and Bersillon, 1996), but with a better quality. In general, surface water is introduced into the aquifer to avoid losing it (great losses occur by evaporation from lakes and silting-up of the big reservoirs) and to re-use it during droughts.

Techniques of artificial aquifer recharge have been used all over the world for over 200 years (Carling and Gustafsson, 1998). To protect against predicted water shortages in many arid and semiarid countries, artificial recharge objectives have been defined (Asano and Cotruvo, 2004; Bize et al., 1972; Bouwer and Pyne, 2005; Carling and Gustafsson, 1998; Detay and Bersillon, 1996; Díaz-Cruz et al., 2006; Grünheid et al., 2005; Kortelainen and Karhu, 2006; Pi and Wang, 2006; Rognon, 2000; Tagina, 2001; Topper et al., 2004). Artificial recharge is used in various countries and has given excellent results: in Belgium (Lebbe et al., 1995), Mexico (Portugal et al., 2006), Great-Britain (O'Shea et al., 1996), California (Tien-Chang et al., 1992), Germany (Seiler, 1996), Spain (Martinez-Santos et al., 2005), etc. Moreover, studies made in different regions have demonstrated the impact of irrigation on the recharge of aquifer systems (Böhlke et al., 2007; Calvache and Pulido Bosch, 1996; Carling and Gustafsson, 1998; Chowdary et al., 2003; Greskowiak et al., 2005; Kendy et al., 2003; Macpherson and Sophocleous, 2004; Ruud et al., 2004; Scanlon et al., 2005, 2006; Zammouri and Feki, 2005) and revealed a clear correlation between the fluctuations of the water-table and the recharge rate by irrigation return flow in various countries (China, Australia, USA, Niger, etc.).

Studies carried out in France in artificial recharge zones along the Seine River have also registered a total elimination of parasites between the raw water used for artificial recharge and the water in the aquifer (Detay and Bersillon, 1996). Kulkarni et al. (2003), describe a pilot recharge programme in India which has considerably improved the water quality in the aquifer where an irrigation well has become a source of drinking-water. Moreover, in Texas, a decrease in nitrate in the aquifer water has been recorded during artificial recharge operations (Alan et al., 2000).

In 2004, Masciopinto (2006), studied artificial recharge of a coastal aquifer in southern Italy where he showed that artificial recharge may stabilise the normal situation while improving exploitation. In fact, after seven years of