Noble Gas Recharge Temperature of Sfax Deep Groundwater (Southeastern of Tunisia)

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Abstract

In the present context of climate change and increasing demand for water, it is crucial to identify the origin, groundwater flow dynamics and mean residence times for sustainable management of water resources. In this study, groundwater residence time and recharge conditions of the deep aquifer of Sfax were investigated using environmental isotopes and noble gases. The results show that Sfax deep groundwater was recharged during cooler period of Late Pleistocene. In broad agreement with evidence from other paleoclimate investigations, the estimated noble gas recharge temperature (NGT) is lower than the present by about 5.5 °C. Oxygen isotopes values of Late Pleistocene are also 1.5‰ lower than modern precipitation.

Keywords

Environmental isotopes • Noble gases • Paleoclimate Late Pleistocene • Tunisia

1 Introduction

As conservative tracers, the study of dissolved atmospheric noble gases (He, Ne, Ar, Kr, and Xe) in groundwater offers a powerful approach of paleo-climate reconstruction [1]. It is a tool to investigate the origin and the conditions during groundwater recharge, in particular the recharge or noble gas temperature (NGT). In fact, their concentrations in the recharge areas of groundwater systems are typically considered to be simply a function of temperature, altitude, excess air, and salinity [2]. However, the estimation of NGT requires a number of corrections and conditions to be satisfied. Different simplified models describing the formation of excess air and its fractionation [3, 4] have been used in diverse paleoclimatic studies. The most used models are the unfractionated air (UA) model [5], the continuous equilibration (CE) model in closed system [3] and the partial re-equilibration model (PR-model) [4]. The objective of this investigation was to determine the noble gas recharge temperature of Sfax deep groundwater located in southeastern of Tunisia using the most appropriate model in combination with stable isotopes ($\delta^{2}H$ and $\delta^{18}O$) and (^{14}C and ^{13}C) carbon isotopes.

2 Settings, Sampling and Analysis

Sfax region is located in south east of Tunisia; it represents the second largest urban area with 1.2 Million inhabitants. It is characterized by a semi-arid to arid Mediterranean climate with irregular and rare precipitations (an annual precipitation average of 239 mm) and mean annual temperature of 19 °C. The geology of the study area is made up of tertiary and quaternary sediments. The aquifer system of Sfax is defined as a multilayered aquifer system, consisting of three aquifers: the shallow aquifer (depth less than 50 m), the middle aquifer (from 60 to 240 m) and the upper Miocene deep aquifer (up to 750 m of depth) [6]. Several sampling campaigns were carried out during 2014–2015. A total of 11 samples were collected from deep groundwater (Fig. 1). Chemical, stables and radioactive isotopes parameters were measured in all the samples.

Samples for He, Ne, Ar, Kr, Xe and $^{3}He/^{4}He$ ratios analysis were typically collected by flushing the water sample through annealed copper tubes, which were then pinched off at either end to prevent atmospheric contamination.

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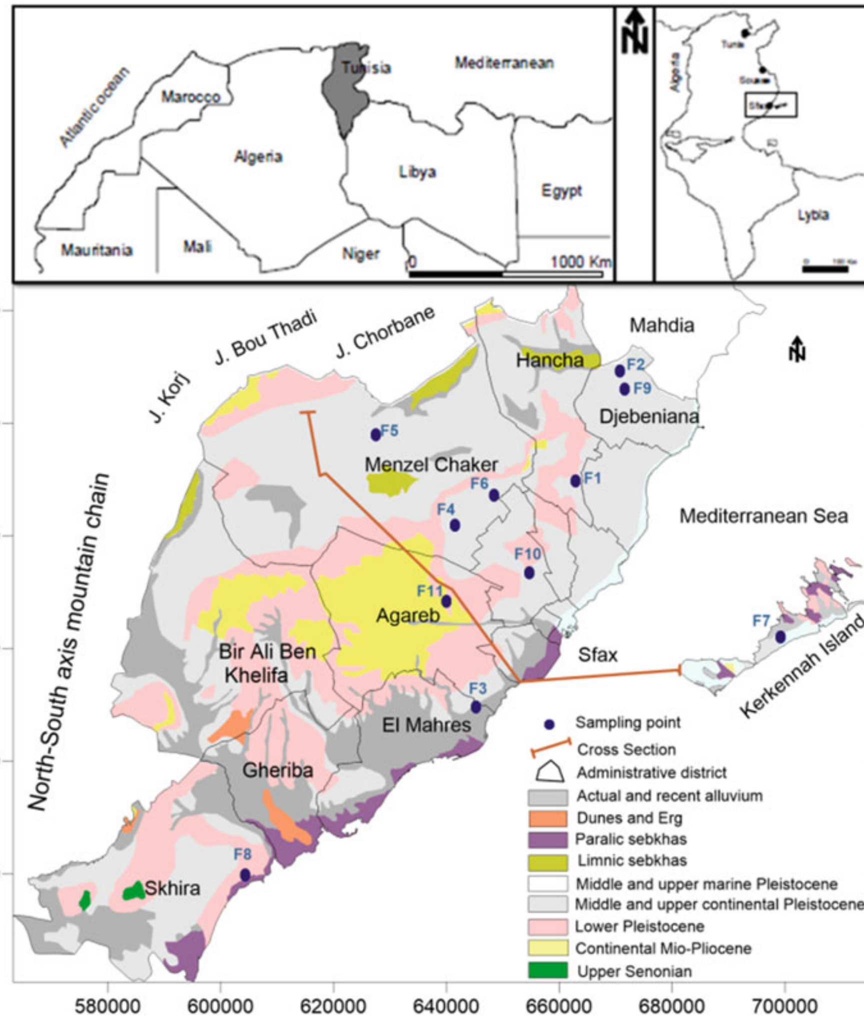
Fig. 1 Location and geological map of Sfax



3 Results

The measured stable isotopes of Sfax deep groundwater are homogenous; $\delta^{18}O$ changes from −6.4 to −6.0‰ with corresponding $\delta^{2}H$ values that vary between −42.3 and −40.5‰ Vs-SMOW. The noble gases concentrations are visualized using box-and-whisker plots (Fig. 2). The measured values were identified as outliers if the distance from the top or bottom 25th percentile was larger than one and a half time of the interquartile range represented by the box in box–whisker plots; the median is represented by a square mark. Outliers as determined by this method are plotted separately. Differences between measured concentrations in replicate tubes are noted in some samples which could be caused by sampling or measuring artifacts. Based on these data the different outliers were removed in order to investigate the recharge temperature.

4 Discussion

Compared to the weighted mean values of $\delta^{18}O$ and $\delta^{2}H$ for Sfax precipitation (−4.6 and −24.5‰) calculated from (1992 to 2016), the stable isotope contents of Sfax deep groundwater are depleted, which could reflect either recharge at higher altitudes and a palaeoclimatic effect (recharge under colder climatic conditions than at present). Further, the low carbon-14 activities measured in all the samples indicating high residence times support the palaeoclimatic groundwater recharge. Several geochemical correction models were applied to convert the measured carbon-14 activities into groundwater ages. For most of the samples, the calculated ^{14}C ages according to different correction procedures appear to be homogenous, providing fairly high confidence in ^{14}C ages. The mean residence times obtained from different correction models are systematically higher than 10 Ka confirming that most of this groundwater

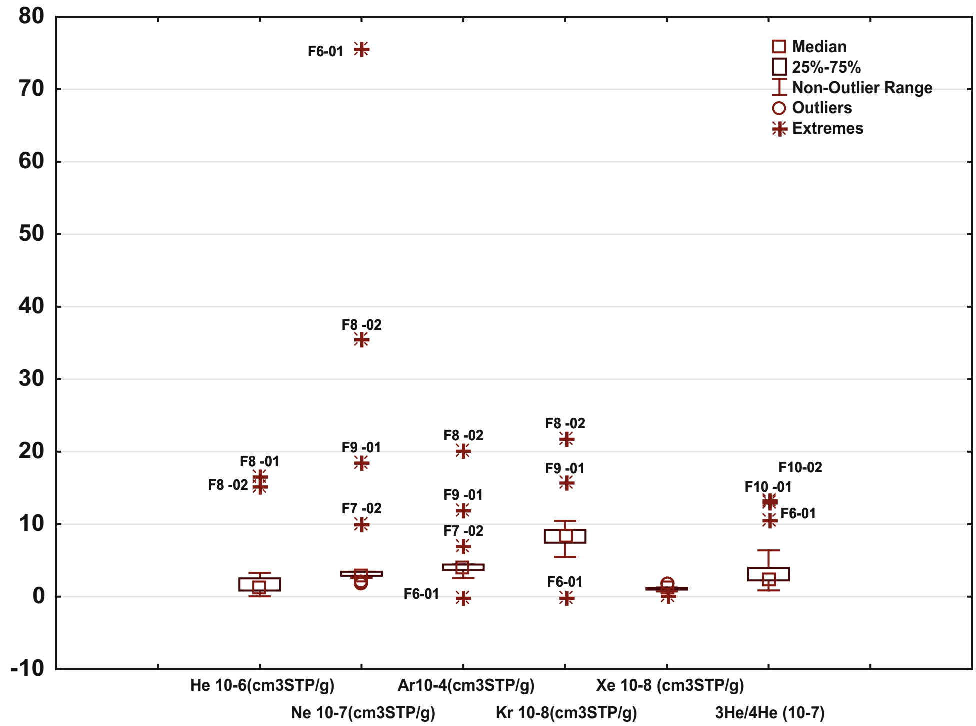


Fig. 2 Box–whisker plots for noble gases concentrations of Sfax groundwater

reserve was recharged before Holocene and the recent recharge of the Sfax aquifer system is very limited.

The analysis of noble gas data with respect to recharge temperature, excess air and its fractionation was performed using the program inoble2.5 by inverse fitting based on χ 2-minimization. According to this test, closed-system equilibration model (CE) [3] is the most appropriate and predicts Ne, Ar, Kr and Xe concentrations compatible with the measured data. The individual uncertainty (1σ) of the noble gas temperature determination varies between 0.1 and 0.2 °C. The calculated NGTs for all samples vary between 13.2 and 16 °C. Consequently, Sfax deep groundwater seems to have infiltrated during the cooler period of the Pleistocene. These palaeo-groundwaters are displaying a mean temperature decrease of 5.5 °C compared to the recharge temperature of modern groundwater in Sfax basin. Accordingly, the oxygen isotope values of Sfax deep groundwater are about 1.5‰ lower than modern precipitation. This transition Pleistocene–Holocene is well characterized in aquifers worldwide.

5 Conclusions

In this research study, environmental isotopes, noble gases, and carbon-14 dating were combined for a better understanding of groundwater flow dynamics and mean residence times of Sfax deep aquifer in southeastern Tunisia. ^{14}C age dating and noble gas data clearly confirm the presence of old groundwater that is recharged during cooler climate of Late Pleistocene. The closed-system equilibration model (CE) is proved to be the most adequate in the case of Sfax deep groundwater to estimate NGT. The calculated values show a decrease of recharge temperature by 5.5 °C compared to the present. Oxygen isotopes values of Late Pleistocene are also 1.5‰ lower than modern precipitation. All these results should be considered for the assessment of the renewability rates and the reliability of these groundwater resources as a major source of water supply in the region over the medium and long-terms.

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