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Research paper

Hydrologic source identification using stable isotope ratios of bottled drinking water in Egypt

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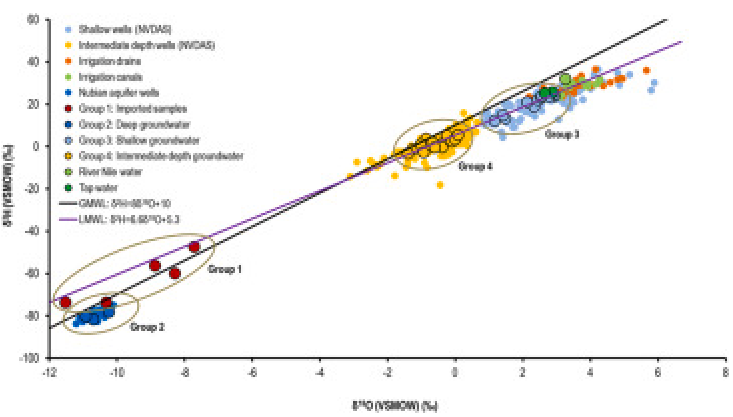
Highlights

- Stable isotopes were used to authenticate the source of bottled water products.
- This is the first isotope ratios database of bottled water distributed across Egypt.
- The study indicates the link between bottled water and local hydrogeology.
- The isotope ratios of the Egyptian brands suggest that they have diverse origins.

Abstract

A convenient way to understand hydrologic source identification is to make use of a suitable tracer. Isotopes of oxygen and hydrogen provide that opportunity since the isotope ratios of the primary source, precipitation, can be modified by post precipitation processes. This approach has been tested by carrying out a comprehensive isotope ratios investigation of domestic and imported bottled water sourced and distributed across Egypt. Our collection of bottled water includes 33 samples distributed under 27 distinct brands. We compare the isotope ratios of the bottled water with the isotope ratios of the reported natural water source of this water. The bottled water isotope ratios preserve information about the water sources from which they were derived. The measured oxygen and hydrogen ratios of the studied bottled water samples range from −11.51‰ to 2.94‰, with an average value of −1.89‰ for $\delta^{18}O$ and from −81.69‰ to 23.94‰, with an average value of −9.54‰ for $\delta^{2}H$. The observed variability of isotope ratios in the bottled water falls within the span of the natural groundwater resources in Egypt, such as shallow and deep groundwater aquifers as well as claimed non-Egyptian sources. In general, the bottled water samples in the data set can be divided into four distinct groups based on their isotope ratios. One group represents imported bottled water brands, and three groups include domestic brands. The first group represents the imported bottled water brands. Their measured isotopic compositions are similar to those of their claimed sources. The second group has the lowest $\delta^{18}O$ and $\delta^{2}H$ values and likely originated from the Nubian aquifer. The third and fourth groups appear to have been sourced from the Nile Valley and Delta aquifer. The third group isotopic content and d-excess values indicate a higher degree of mixing with evaporated return flow water. The results provided in this study indicate the diverse hydrogeology of the local bottled water brands. This promises extending the approach to several sites globally.

Graphical abstract



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Introduction

Good quality drinking water is a fundamental requirement for human beings, and it is the major constituent of body cells, tissues, and fluids (Gleick 2004). Consumers often get their drinking water from two main sources, namely groundwater and surface water. Either of these can be further distributed as tap water, bottled water, or filtered water. Nowadays, as the healthy lifestyle becomes increasingly popular and concern about the quality of drinking water grows rapidly, bottled water has gained increased popularity.

Bottled or packaged water is quality-assured drinking water that is intended for human consumption. Usually originates from natural fresh water reservoirs (surface water, groundwater, springs, and glacial melts). The water is sealed after collection in plastic or glass water bottles with little or no further purification. The sizes of the bottled water range from small single serving bottles to large carboys. Consumers choose between varieties of bottled water based on several reasons, like taste, quality, and mostly convenience. The bottled water industry has been around for a long time, and the world market for bottled water has grown rapidly. It is considered a global billion dollar business and is expected to witness notable growth in the coming years (Ikem et al., 2002; Versari et al., 2002; Bertoldi et al., 2011; Kermanshahi et al., 2011). About 1500 different brands originating in over 250 countries have been documented (Rangarajan and Ghosh, 2011). The consumption of bottled water has been dramatically increasing and represents an important component of human dietary intake worldwide (Hu et al., 2011; Ballantine et al., 2019). The global consumption of bottled water is estimated to have surpassed 100 billion gallons (379 billion liters) for the first time in the year 2018, with a global average consumption of 14gallons (53L) per person during the year 2018 (International Bottled Water Association (IBWA), 2018).

Egypt has a similar trend of increasing bottled water consumption, promising to be the most significant future growth market in the region. The main reason for this growing trend is the presumed safety of bottled water over tap water, especially in light of significant tourism. However, bottled water often presents the potential for fraud and product misrepresentation that may be physically or economically harmful to consumers (Bowen et al., 2005; Dotsika et al., 2010; Lema and Wodaje, 2018). For example, doubts will always remain as to whether a bottle of water is actually from a spring fed by a deep artesian aquifer, local surface water, or local municipal water supply. Several local bottled water brands are available and sold in the Egyptian market. Large and populated areas like Greater Cairo represent an important market where all of the brands are found and sold.

Additionally, some international brands are also found in the Egyptian market, however these brands are usually more expensive than tap water or local bottled water brands. The bottled water industry in Egypt is subject to comprehensive government regulations, and bottled water brands are continuously investigated by the government (Egypt's Health Ministry as well as Egypt's Consumer Protection Agency). In recent years, some products from the Egyptian bottled water brands were found to be contaminated and unsafe for human consumption, and consequently, some companies were suspended or forced to cut their production (Abd El-Salam et al., 2008a, 2008b; Hassan et al., 2013; Ibrahim et al., 2014; Amira, 2015).

Stable isotopes of oxygen and hydrogen in water have been extensively used to understand the hydrologic cycle in many places worldwide, and the findings provide a recognizable signature relating to various processes in the water cycle (Craig, 1961; Dansgaard, 1964; Gat et al., 1995; Clark and Fritz, 1997; Hoffman et al., 2000). The oxygen and hydrogen isotopes are not only a powerful tool to study the hydrologic cycle but can also have implications in our daily lives, for example, in the human diet (Bowen et al., 2005; Ehleringer et al., 2015; Cerling et al., 2016) and medical applications (Cogo et al., 1999; Schellekens et al., 2011; Krishnamurthy et al., 2017).

Generally, groundwater and surface water that constitute bottled water mimic local precipitation isotopically unless secondary processes occur prior to recharge (Clark and Fritz, 1997; Magdas et al., 2009). It should be noted that groundwater may be very old and recharged thousands of years ago, unrelated to the present hydrologic cycle. In this study, we explore the possibility of using the isotope data from bottled water to identify the hydrologic source of bottled water sold in Egypt. Our approach makes use of the knowledge of factors that control the stable isotope ratios in precipitation and post precipitation processes (Craig, 1961; Dansgaard, 1964; Merlivat and Jouzel, 1979; Clark and Fritz, 1997). In addition, this study sheds light on the claims made by select vendors of bottled water in Egypt. In other words, we investigate whether the claims of the bottled water source, such as “water from deep wells,” “water from mountain springs,” and so on, can be sustained using isotope ratios. The objective of this research is twofold, namely to use stable isotopes as a tool to examine the source of bottled water in the study area (hydrologic connectivity) and to extend the information to possibly verify the veracity of the claims regarding the authenticity of these water.

In this investigation, a comprehensive analysis of bottled water across Egypt was carried out to understand its isotopic characteristics. Here, we also used the stable isotope database of precipitation, tap water, surface water, and groundwater in Egypt to trace the source location of the bottled water sourced across Egypt. This demands knowledge of the hydrogeology and stable isotope compositions of the major aquifer systems in Egypt. The stable isotope compositions of the major aquifer systems in Egypt are discussed below.

Section snippets

Sample collection

A total of 33 bottled water samples from 27 different brands were obtained from the Egyptian market in 2019. Some brands were sampled as duplicates from different bottle sizes or supermarkets. Available records of source locations suggest that our sample set includes bottled water from three countries other than Egypt. These are Romania, Italy, and France. The distribution of the samples is shown in Fig. 1. Table 1 summarizes the sample brands, claimed country of origin, source water and…

Major aquifer systems in Egypt

Groundwater constitutes the second important source of freshwater in Egypt after the River Nile, and represents about 12% of the total water supply in Egypt (SEAM, 2005; Abo-El-Fadl, 2013; Mohammed et al., 2022a). The major groundwater systems in Egypt are: the Nile Valley and Delta Aquifer System (NVDAS); the Nubian Sandstone Aquifer System (NSAS); the Fissured Carbonate Aquifer; the Moghra Aquifer; the Coastal Aquifer; and the Hardrock Aquifer. These aquifer locations are shown in Fig. 2. The …

Distributions of $\delta^{18}O$ and $\delta^{2}H$

The oxygen and hydrogen stable isotope values of the bottled water samples analyzed in this study are presented in Table 1. The $\delta^{18}O$ and $\delta^{2}H$ values range from −11.51‰ to 2.94‰ with an average of −1.89‰ for $\delta^{18}O$ and from −81.69‰ to 23.94‰ with an average of −9.54‰ for $\delta^{2}H$. The d-excess values of the bottled water samples in this study range from 0.06‰ to 18.40‰ with an average value of 5.54‰.

The $\delta^{2}H$ – $\delta^{18}O$ relationship is plotted in Fig. 3 along with the Local Meteoric Water Line (LMWL) (LMWL…

Conclusions and caveats

The oxygen and hydrogen isotopic compositions of bottled water promise to be useful tool for market regulators. In some situations, such as in this study, the isotope-based studies might also provide a link to the local hydrogeology. This study provides the first and most up-to-date application of stable isotopes as a tool for authenticating and understanding the source of bottled water products in Egypt, a major tourist destination.

Our analyses of the isotope ratios of the collected bottled…

CRediT authorship contribution statement

Abdel Mawgoud Mohammed: Writing – original draft, Software, Resources, Methodology. **R.V. Krishnamurthy:** Writing – review & editing, Supervision, Methodology.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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