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Geochemical modeling of evaporation process in Lake Qarun, Egypt

Mahmoud S.M. Abdel Wahed [a,b,*], Essam A. Mohamed [b], Mohamed I. El-Sayed [b], Adel M'nif [c], Mika Sillanpää [a]

[a] Lappeenranta University of Technology, LUT Chemistry Department, Laboratory of Green Chemistry, Sammonkatu 12, FI-50130 Mikkeli, Finland
[b] Beni-Suef University, Faculty of Science, Geology Department, Egypt
[c] Centre National de Recherche en Sciences des Matériaux, Technopole Borj Cedria, B.P.73, 8027 Soliman, Tunisia

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ABSTRACT

Lake Qarun is an inland closed saline lake. It lies within the Fayoum Depression in the Western Desert of Egypt. Evaporation modeling has been carried out using PHREEQC to simulate the geochemical evolution of surface drainage waters inflow towards lake water. In the case of Lake Qarun, it is the first attempt to carry out such kind of modeling. Performance of this model helped to address the different sources of dissolved major ions to Lake Qarun and to identify the mechanisms control the lake's water chemistry. The model demonstrated that evaporation–crystallization process is the main mechanism controlling the evolution of lake water chemistry where major ions Na^+, Mg^{2+}, Cl^- and SO_4^{2-} have been built up in the lake by evaporation while Ca^{2+} and HCO_3^- are depleted by calcite precipitation. Moreover, the simulated model reproduced the real data observed in Lake Qarun except in the case of SO_4^{2-} which is in real more enriched in the lake than the model output. The additional source of SO_4^{2-} is reported to be from groundwater. The models result agreed well with the modified evolutionary Hardie and Eugster's scheme (1970) in which the final major composition of Lake Qarun water is Na–Mg–SO_4–Cl type. In future, the monitoring of Lake Qarun chemistry with detection of any other sources of elements and/or local reactions inside the lake can be detected by performing the simulated evaporation model reported by the present study.

1. Introduction

Closed lakes are exclusive features of the arid and semiarid zones where annual evaporation exceeds rainfall. Closed lakes are salty with varying degrees. This is caused by evaporation exceeding inflow, by the inflow being saline or both (Eugster and Hardie, 1978). Based on major ions such as Na^+, K^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, and HCO_3^-, Hardie and Eugster (1970) generalized an evolutionary model that interprets the chemistry of waters undergoing evaporation in terms of a succession of chemical divides. A chemical divide is a point in the evolution sequence of brine at which precipitation of a mineral depletes the water in certain cations or anions and further evaporation moves the solution along a distinct pathway. The main concept of chemical divide is that whenever a binary salt is precipitated during evaporation, and the effective ratio of the two ions in the salt is different from the ratio of the concentrations of these ions in solution, further evaporation will result in an increase in the concentration of the ion present in greater relative concentration in solution, and a decrease in the concentration of the ion present in lower relative concentration (Drever, 1982). Although there are many modifications of the basic Hardie-Eugster evolutionary model, this study will only be based on the modification proposed by Drever (1982).

Simulated evaporation of natural waters by PHREEQC is widely used because of its capability of removing moles of water from the solution (Parkhurst and Appelo, 1999; Smith and Compton, 2004). PHREEQC is publicly available, expandable, and well documented geochemical modeling code with an extensive thermodynamic database. Also, the capabilities of PHREEQC include simulating the chemical behavior of aqueous solutions composed of all major solutes.

Lake Qarun, the object of the present study, is one of the largest inland saline closed lakes in the North African Great Sahara. This lake is the deepest area in the River Nile flood plain, making it the final destination of both natural (subsurface flow) and artificial (agricultural) drainage in the Fayoum Depression (Fig. 1). Since the lake has no natural outlet (Wolters et al., 1989), the drainage water impounded is subject to concentration by evaporation. An average of about 385×10^6 kg of salts are washed out annually from

* Corresponding author at: Lappeenranta University of Technology, LUT Chemistry Department, Laboratory of Green Chemistry, Sammonkatu 12, FI-50130 Mikkeli, Finland. Tel.: +358 503484584.

E-mail addresses: mahmoud.abdel-wahed@lut.fi, m.abdelwahed80@yahoo.com (M.S.M. Abdel Wahed).

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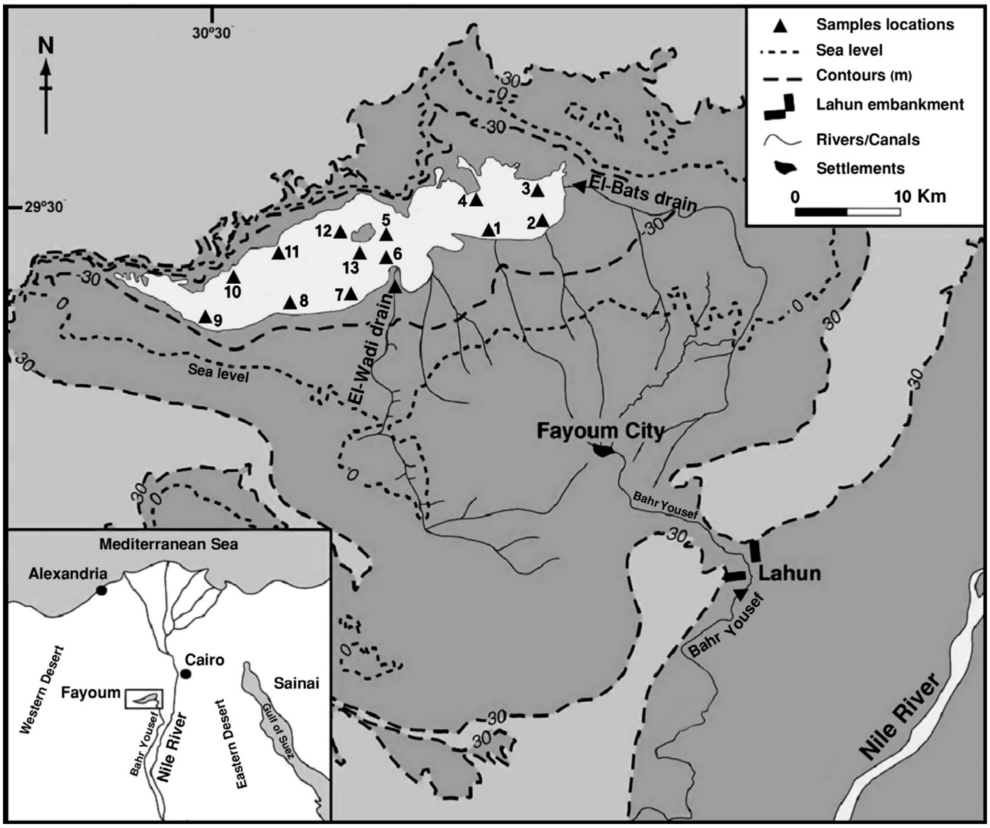

Fig. 1. Location map of Fayoum with sampling sites (triangles) and sampling codes (numbers inside the lake).

cultivated land and conveyed to the lake (Meshal, 1977). A volume of fresh water nearly equal to that of the inflowing water is lost annually from the lake through evaporation while the dissolved salts are left in the lake (Meshal, 1977). The lake brine is subjected to gradual evaporation resulting in an increase in its salinity (Gorgy, 1959). The current salinity of Lake Qarun is ≈35 g/kg on average. The increase in salinity has been attributed mainly to the evaporative concentration of drainage water within the lake (Ball, 1939; Meshal, 1977; Rasmy and Estefan, 1983).

The aim of the present work is to simulate an evaporation model using PHREEQC software along with the Hardie-Eugster evolutionary model to assess the geochemical evolution of Lake Qarun water. To test the validity of the simulated PHREEQC model, its output results will be compared with the real and experimental data of the lake water. The studying of this simulated model will be useful in different ways such as (1) to identify the geochemical processes controlling Lake Qarun chemistry, (2) to define the different sources of elements to the lake, and (3) to anticipate future evolution of the lake water composition with any change in the chemistry and inflow rate of drainage water to the lake, as well as changes in the evaporation rate.

2. Study area and methods

2.1. Site description

Lake Qarun is a closed saline basin located between the longitudes of 30° 24′ & 30° 49′ E and latitudes of 29° 24′ & 29° 33′ N in the lowest northern part of the Fayoum Depression, about 95 km south west of Cairo (Fig. 1). The lake is at 43 m below sea level. It has an irregular elongated shape of about 45 km length and 6 km mean width with an average area of about 240 km^2. The water depth ranges from 5 to 8 m, decreasing toward the lake shores. The River Nile is the main source of fresh water, reaching the Fayoum region via Bahr Yousef (Fig. 1). Agricultural returns are collected as drainage water and passed into Lake Qarun from the south and southeast through two main drains, El-Wadi and El-Bats, with other minor drains between them (Fig. 1). To the north, the area is completely covered by sand and rock with several exposures of diatomite (Aleem, 1958).

Lake Qarun water is currently alkaline, saline and turbid. The lake comprises two main basins. The western basin has a maximum depth of 8.4 m whereas the eastern basin is shallower with a maximum depth of less than 5 m (Flower et al., 2006). The water temperature ranges seasonally between about 15 and 33 °C (Ball, 1939; El Sayed and Guindy, 1999).

2.2. Climate

The studied area lies in Egypt's arid belt characterized by hot long dry summer and mild short winter, in addition to low seasonal rainfall and a high evaporation rate. Fayoum district climactic data shows that the mean annual rainfall is 7.2 mm/year (Ali and Abdel Kawy, 2012). Currently, the mean minimum and maximum annual temperatures are 14.5 °C and 31 °C, respectively. The lowest evaporation rate (1.9 mm/day) is recorded in January while the highest value (7.3 mm/day) is recorded in June and the annual mean relative humidity varies between 50% and 62% (Ali and Abdel Kawy, 2012). The climate in the Lake Qarun region is generally dry (Baioumy et al., 2010).

2.3. Hydrology

The irrigation and agricultural system in the Fayoum region depends mainly on Nile water. Fayoum City, the principal town