Water management in the System of the River Nile in Egypt assisted by isotopic and geochemical data

Gestion des eaux du système fluvial du Nil en Égypte assistée par des données isotopiques et géochimiques

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RÉSUMÉ

Le développement durable en Égypte doit être abordé à travers la gestion intégrée des eaux dans le Système de Fleuve du Nil. L'objectif de ce papier est d'identifier des problèmes et des besoins qui sont jugés importants pour l'amélioration de l'utilisation des eaux au pays. Des données des isotopes du milieu (^{18}O, ^{2}H, ^{3}H, ^{13}C, ^{14}C and ^{34}S) et des données géochimiques (analyses hydrochimiques des eaux naturelles, recueil des solutés des colons BTC et leur modélisation) ont étés utilisés afin d'étudier des eaux souterraines par rapport à l'origine de sa minéralisation, la modification de composition ionique et la salinité totale des eaux saumâtres. Le dépouillement des résultats a révélé la présence des eaux du Nil anciennes dans l'aquifère Pléistocène, l'intrusion des eaux marines côtière au nord, fuite des eaux fossiles à partir des grès Nubien, percolation des eaux de l'aquifère libre vers l'aquifère semi-confiné et des effets biogéniques. En outre, la recharge dans la nappe aquifère Pléistocène a été déterminée. La technique BTC pour le recueil des solutés à travers des sédiments a montré que les ions échangeables et la concentration des espèces dissoutes dans l'effluent peuvent être remaniés pour améliorer la qualité des eaux. Un dispositif multi-colonnes conséquent est proposé pour le recyclage des eaux usées. Ce travail peut être pris en compte dans la gestion de pompage, augmenter l'approvisionnement en eau en terrains désertiques adjacents, et améliorer la qualité des eaux agricoles usées au bassin septentrional du Nil en Égypte.

ABSTRACT

Sustainable development in Egypt is to be addressed through integrated water management in the River Nile System. The purpose of this paper is to identify problems, knowledge, gaps and needs that deemed important to improve water management in the country. Environmental isotopes (^{18}O, ^{2}H, ^{3}H, ^{13}C, ^{14}C and ^{34}S) and geochemical data (surface and groundwater hydrogeochemistry, experimental work and modeling of the breakthrough curve, BTC) were used for studying groundwater resources and recharge, origin of water salinity, modifying the ionic composition and the TDS of brackish water. The collected samples have showed presences of elder Nile-water in the Pleistocene aquifer, intrusion of marine groundwater in the coastal reaches, upward movement of fossil groundwater from the Nubian sandstone-aquifer, downward leakage from the unconfined to the semi-confined aquifer and biogenic effects. Recharge rate estimation of the Pleistocene aquifer was also attempted. The BTC technique was used on fine sediment to follow the modification of the ionic composition of brackish water. To reduce wastewater salinity, a low-cost multi-column device is proposed for drainage water recycling. The approach used is useful to improve pumping, to enhance water supply to surrounding desert fringes of the Nile system and to protect water quality.

KEYWORDS

BTC and desalination, hydrogeochemistry, isotope hydrology, Nile water in Egypt.

INTRODUCTION

Egypt has a water crisis that is continuously developing under constantly escalating demographic pressures. One of the solutions of that national problem is to implement an integrated use of surface and groundwater resources. The intrusive River Nile discharge (55.5billion m^3y^{-1}) into Egypt is almost the unique source of water in the country since local rainfall is very scarce. A planned pumping policy for groundwater of Nilotic origin in the Pleistocene aquifer of the Nile Delta and Valley, and their adjacent desert fringes, seems an interesting remedy to satisfy the water demand gap, and to lower the piezometric level that increased by about 10m during the last 140years due the introduction of omnipresent perennial irrigation system and lack of equivalent drainage network. This hydrologic situation gives place to soil salinization and related engineering and health problems. In addition, the recycling of drainage water seems an interesting solution. However, poor drainage water quality may stand against the second solution. This work introduces data and interpretation dealing with those concepts. However, the water crisis in the country is overwhelming and needs more efforts before a compromised approach can be put into action.

METHODS AND MATERIALS

Two hundred water samples were collected from surface water (River Nile, irrigation and drainage creeks, tile-drainage pipes, lakes and brines) and groundwater (Pleistocene and Miocene aquifers of the Delta and Valley and their adjacent desert). All samples were analyzed for major ions, pH and other common water quality parameters. Moreover, layers of 30 soil profiles were sampled to the shallow water table (~1m deep) and were analyzed for chemical composition of paste-extracts. Water samples were studied for their contents in ^{18}O and ^{2}H. Half of water samples were measured for ^{13}C, ^{34}S contents and for the radioactive isotope ^{3}H. Only 24 samples were measured for radiocarbon, ^{14}C.

RESULTS AND DISCUSSION

The isotopic data indicates a close relationship between input components (surface water flowing from the river to smallest irrigation channels) and output components (drainage water and groundwater recharge). It became clear that the main aquifer is subject to marine intrusion in the coastal zone and to fresh fossil-water leakage from thee Nubian aquifer, as elucidated by isotopic discontinuity and mixing, Figure 1. The wide range of the observed radiocarbon activity, $A^{14}Cpmc$, Figure 1 (a), is showing a fossil water component and a modern to elder Nilotic water component. The fossil component has dead carbon and it is highly depleted in ^{18}O and ^{2}H. This phenomenon is known in the Sahara groundwater and attributed to old recharge that took place under ancient climate with more humid and lower temperature conditions than present; recharge that almost stopped 40 thousand years BP. Groundwater of Nilotic origin is subdivided into recent and elder constituents, on a different time-scale. The time barrier, in the last case, is related to huge storage of Nile water discharge into Lake Nasser that started after the completion of Aswan High Dam by 1970. The pre-1970 groundwater is somewhat depleted in ^{2}H and ^{18}O and has some bomb-tritium, Figure 1 (B). Groundwater recharged after 1970 seems exposed to intensive evaporation as expected for a huge Lake (~5000km^2 in area) in the Sahara. Higher than expected tritium content in few pre-1970 groundwater samples, compared to low tritium in some post-1970 samples, is due to rapid waning of tritium in precipitation that marks the post-1970 Nile water tritium content. The obtained ^{13}C data reveals biogenic impact of the grown C4 and C3 crops (delta-^{13}C/PDB values lower than that of the atmospheric CO_2g, of -8 per mile/PDB, by 10-15 per mil). The observed deta-^{34}S values/CD indicate significant bacterial reduction of sulfates in the northern sector of Delta aquifer, where the Holocene clay-cap is very thick (>80m). Northward, the thick clay-cap is forcing the aquifer to behave like a confined aquifer, whereas the thin clay-cap in the middle/southern sector of the Delta admits the aquifer to show a semi-confined behavior. The hydrochemical data indicates a wide range of ionic strength (IS) with extreme values for alkaline brines in the Natroun depression to southwest of the Delta. This depression, in desert adjacent to the west of the Nile Delta, works as a western porous exit for elder Nilotic groundwater seeping from the main Delta Pleistocene aquifer, and as a fracture northward exit for fossil water from the vast Miocene Nubian sandstone aquifer through some fractures. The shallow water table, under the Delta saline soils, has some samples with high ionic strengths. The extremely wide range of surface water salinity and chemical composition, spreading from (IS) close to that of the Nile water and / or (IS) of aqueous solution saturated in Gypsum, to samples saturated in Trona and Halite in Natroun brines, is outstanding. This finding reflects marine *versus* continental pathway of ionic composition development.

The BTC runs, Figure 2, show a strong potential not only for modifying the exchangeable cations in

soils but also as good potential for the use of a multi-column device for correcting the wastewater ionic composition, and ultimately for the decreasing TDS, and for the desalination of drainage water through ion exchange. Details of local application of that simple desalination technique are given elsewhere.

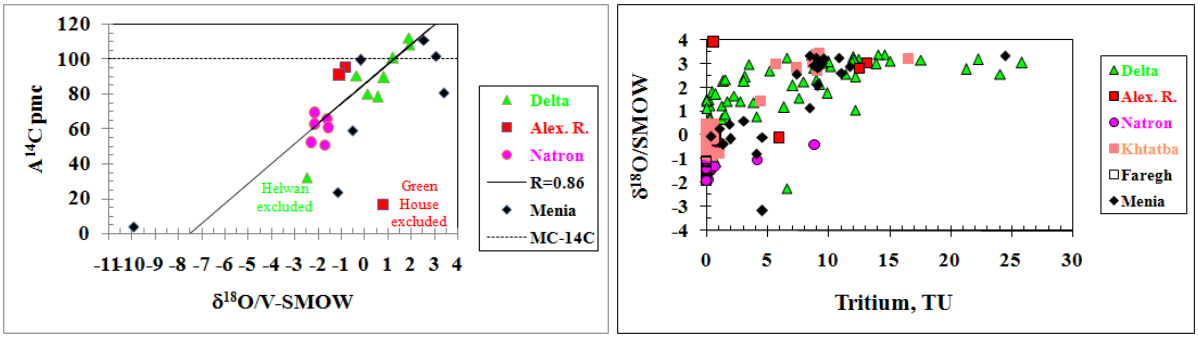

Figure 1. Stable and radioactive environmental isotope data for Nile Delta and Valley groundwater
(A) Fossil and old samples with low to very low A^{14}Cpmc, also have low to very low delta-^{18}O values.
(B) Elder Nile water in the Pleistocene aquifer has some or no tritium, and delta-^{18}O values close to zero per mil.

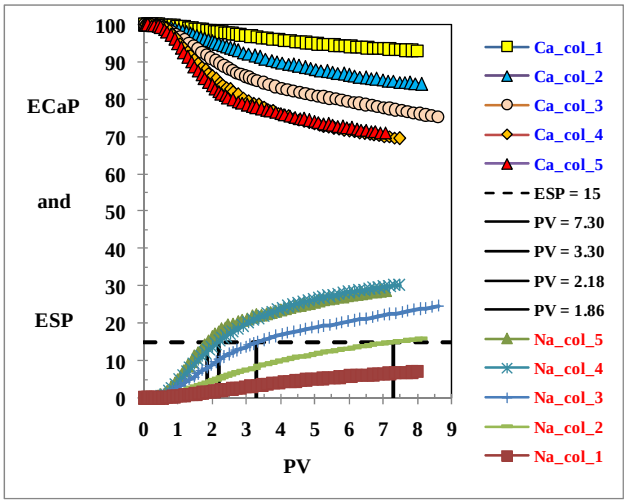

Figure 2. Initially Ca-saturated BTC columns show Ca *versus* Na exchange on marginal sediments. PV = Pore volume. ECaP and ESP = Exchangeable Ca % and Exchangeable Sodium %, respectively.

CONCLUSIONS

The coupled isotopic and hydrogeochemical observations provided a precious guide for planning groundwater pumping both from the Nile Delta and Valley aquifer and the Nubian aquifer, in adjacent desert fringes, in order to combat salinization in the irrigated soils on one hand, and to supply discharge of more water to satisfy increasing demand for irrigation water outside the historically cultivated lands in Egypt on the other hand. The BTC runs indicated that recycling of drainage water through appropriate desalination devices would be sensibly used to improve drainage water quality.

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