論 文 の 内 容 の 要 旨

論文題目　**Impact of Surface Development on Subsurface Environment in an Arid Climate: Consideration Based on Groundwater Quality and Isotopic Signals at the New Reclaimed Land, Eastern Nile Delta, Egypt**

（ 乾燥地域における地表開発が地下環境に与える影響：エジプトナイルデルタ東部の開発地域を対象とした地下水質並びに同位体情報を用いた検討 ）

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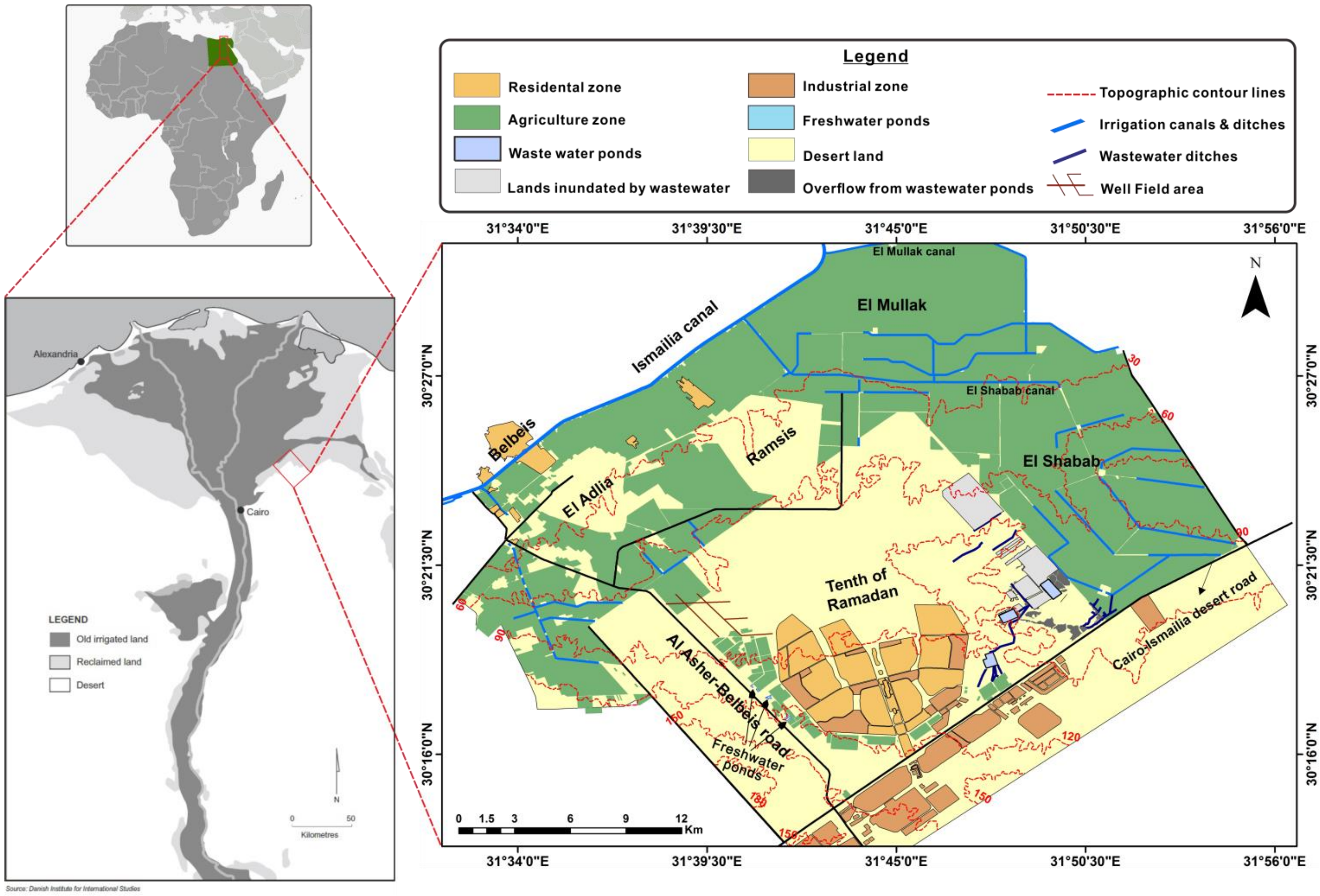
Groundwater is increasingly recognized as a main factor in dryland development, i.e., land reclamation and cultivation, in many arid countries where the surface water resources are especially limited or scarce. Throughout the rapid urban and agricultural development, changes of groundwater quantity and quality often occur by the increase of groundwater abstraction and the introduction of new sources of recharge. Given the aforementioned complex set of environmental and anthropogenic issues, information required to diagnose the drivers of groundwater quality/quantity degradation and aquifer depletion, and to assess management and/or protection options are usually difficult and complex. This is even more relevant for groundwater aquifers in areas that were historically called “deserts” and represent nowadays some of the most cultivated lands with high economic significance in arid environments. In this context, understanding the impact of land development on groundwater aquifer systems will provide the basic knowledge to achieve the sustainability of groundwater use and to manage the risks of its degradation.

Over the last six decades, Egypt has adopted aggressive policies to exploit their surface water and groundwater with associated increase of cultivated and reclaimed lands that were originally deserts. As a result, desert fringe of the eastern Nile Delta, south of the Ismailia canal, is now home to four agricultural projects, i.e., El Adlia, El Mullak, Ramsis and El Shabab, in addition to new urbanized and industrial settlements, the Tenth of Ramadan city (Fig.1). These surface activities have expanded over the Quaternary aquifer, the second water resource after the Nile River in Egypt, without proper protection and management plans. Salinization, contamination, upconing of deep saline water, and water level changes are aspects of mismanagement of the Quaternary aquifer that may increase with continuous development and expansion of the area. Regionally, the future challenge to the sustainability of water resources in these new lands will likely be the shortage of surface water supplies by the year 2017 to cope with the increasing demand. This in turn will place significant pressure on aquifers. The different methodologies, i.e., environmental tracers, hydrochemistry, multivariate analysis techniques, water balance estimation, and geophysics, were applied to the Quaternary aquifer system underlying this new reclaimed land with complex array of human activities, such as agriculture, industry, and unlined wastewater ponds, to resolve the impact of land development on groundwater environment through the identification of groundwater end-members and their mixing processes.

Fig. 1 Location and main land use of the study area



Using a set of chemical and isotopic (δ^2H, $\delta^{18}O$, $\delta^{13}C$ and ^{14}C) data in tandem with multivariate data analysis, source components in groundwater of the Quaternary aquifer system underlying the new reclaimed land, eastern the Nile Delta, Egypt, were estimated. Electric conductivity (EC) and stable isotopic characteristics of water in the Quaternary aquifer varied widely and were used to group the samples into four clusters by applying hierarchical cluster analysis (HCA). The water groups were then examined through principal component analysis (PCA) together with the information on the groundwater from the Miocene aquifer, water from the Ismailia canal, old Nile water, and wastewater. The overlap of clusters 1 and 2, i.e., low EC groundwater, with the old Nile water and water from the Ismailia canal in PCA space indicated that groundwater in the northern parts of the Quaternary aquifer are hydraulically connected with water in the Ismailia canal. Stable isotopic depletion of water of subcluster 1.3 suggested a different source other than the Nile water. Clusters 3 and 4, i.e, high EC groundwater, were grouped with the groundwater of the Miocene aquifer in PCA space to infer the hydraulic connection with the groundwater in the Miocene aquifer, mainly in the southern part of the study area. Cluster 4 samples were stable-isotopically enriched and showed high nitrate concentrations. Also, the cluster 4 samples were distributed in the agricultural area where treated/untreated wastewater has been supplied for irrigation. The information obtained from the analysis of city water balance and recent geophysical data suggested the possibility of wastewater infiltration, which may explain the characteristics of cluster 4 samples. Northward increasing trend of ^{14}C and the lowest ^{14}C values reported in southern portion, i.e., cluster 3, of the Quaternary aquifer confirmed the stated mixing processes. Subcluster 1.3 was interpreted to be the "native" groundwater component of the Quaternary aquifer from their plotted zones in PCA space, δ^2H-$\delta^{18}O$ plots, and $\delta^{18}O$-Cl^- plots. Overall, five different sources were introduced to the Quaternary aquifer in the area, i.e., native groundwater in the Quaternary aquifer, groundwater in the Miocene aquifer, the recent Nile water from the Ismailia canal, the old Nile water, and wastewater. Accordingly, future exploitation and protection policies of this aquifer will have to account for the salinity factor from the Miocene aquifer, the pumping scheme at the well field area to prevent upconing of high-salinity Miocene aquifer water, the influence of water recharged from the wastewater ponds, together with the future shortage of surface water.

Estimating the end-members, following the applied methodology, helps to develop better insights into the functioning of the groundwater system and how anthropogenic forcing through land-use change may imperil or help protect the health of the hydrologic system in arid to hyper-arid environments. Main part of assessing the sustainability of such new reclaimed arid lands will therefore be assessing and regular monitoring the groundwater mixing phenomena to forewarn of the hazards of water mishandling.