Multidisciplinary geophysical surveys for 3D hydrogeological conceptual model reconstruction in areas contaminated by fluoride in Nakuru area, East African Rift System (Kenya)

Stefano Bernardinetti[1], Chiara Gargiulo[1], Alessio Barbagli[1], Andrea Zirulia[1,2,3], Tommaso Colonna[1,3,4], Enrico Guastaldi[1,3,4], Paolo Conti[1], Lisa Serri[1], Stefano Bonfigli[1], Claudio Zanghirati[1], Luigi Antolini[1], Elias K. Ucakuwun[5], Stefania Da Pelo[2], Roberto Balia[6], Marco Pistis[2], Giorgio Ghiglieri[2]*

[1] *CGT – Centro di GeoTecnologie, Università di Siena, San Giovanni Valdarno (AR), Italy.*
**Corresponding email: bernardinetti@cgt-spinoff.it*

[2] *Università degli Studi di Cagliari, Dipartimento di Scienze Chimiche e Geologiche, Monserrato (CA), Italy*

[3] *Geoexplorer Impresa Sociale S.r.l., Arezzo, Italy*

[4] *CGT SpinOff S.r.l., Arezzo, Italy*

[5] *University of Eldoret, Department of Environmental Earth Sciences, Eldoret, Kenya*

[6] *Università degli Studi di Cagliari, Dipartimento di Ingegneria Civile, Ambientale e Architettura, Cagliari, Italy*

ABSTRACT
An extensive geophysical fieldwork was performed in Nakuru county (Kenya), Autumn 2018, aiming to study the shallow structure of the rift valley, within the framework of FLOWERED activities, an H2020 European Commission project (www.floweredproject.org). The overall objective of the project is to contribute to the development of a sustainable water management system in East African Rift areas affected by natural fluoride contamination.
The investigated area is located in South-western Kenya near Nakuru, in the central part of the Kenya Rift. The area is characterized by a thick volcano-sedimentary succession of Pleistocene-Quaternary age, with volcanic rocks as lavas (phonolites, basalts, and trachytes) and pyroclastic flows and fall deposits (tephra, tuffs and fall deposits), intercalated with alluvial gravel and sands. The geophysical fieldwork was designed to implement a local detailed three-dimensional hydrogeological model of Nakuru area. We performed resistivity surveys at two different scales by using electrical resistivity tomography (ERT) and Hybrid-Source Audio Magnetotelluric (HSAMT), integrated by single station passive seismic measurements (HVSR). Overall, the performed surveys were helpful to delineate: a) depth and thickness of aquifers, b) aquitards or confining units and c) locating preferential fluid migration paths such as fractures and fault zones (Ghiglieri et al., 2017).

Keywords: geophysics, magnetotellurics, geoelectrics, passive seismics, hydrogeology, fluoride contamination

METHODS

To integrate the existing hydrogeological conceptual model, we perform 3 different geophysical methods: ERT and HSAMT for resistivity measurements, HVSR for passive seismic measurements. The surveys were planned taking into account main geological/hydrogeological targets (Ghiglieri et. al., 2017) and logistical constrains, i.e. the technical suitability of survey areas according to geophysical methods applied. Resistivity measurements (i.e. ERT and HSAMT) were located across the rift valley area along three different lines, two sub-orthogonal to the main geological features, oriented North-South, and one oriented North west – South east crossing the entire valley and reaching the reliefs to the eastern part of the rift. HVSR were wide spread across the study site in order to cover as much area as possible. Electrical and electromagnetic techniques are commonly applied in groundwater research due to the correlation between electrical properties, geological features and fluid contents. Electrical resistivity maps obtained using electrical or electromagnetic surveys, are used in hydrogeological studies in order to recognize different water sources based on their salinity differences (see for instance Bauer et al., 2006, or Befus et al., 2012). HVSRs, a method widely used for a quick survey of seismic-amplification effects, were also performed at dozens of locations across the whole study area to achieve information about the spatial variability of superficial deposits thickness.

RESULTS

Due to the geological/geophysical complexity of the site, the best state-of-the art rendering for the geophysical data was used as preliminary results. In such area, the presence of complex water circulation and alteration of minerals make hard the interpretation of resistivity variations. In fact, bulk resistivity is mainly related to ionic conduction and surface conduction in presence of clayey minerals. However, we distinguished few principal geophysical features consistent with geological outcroppings and literature works of the study area. Although the best colour scale of resistivity results differs slightly for each single technique (i.e. ERT and MT), we unified both ranges in order to identify a common colour scale, useful for the comparison and in the interpretation phase. By the integration of geophysical methods, it was possible to obtain valuable information about site-specific conditions within the thickness of the exploited contaminated aquifers. These data allow to refer the hydrogeophysical framework to the different situations affecting wells and the relative concentrations of fluoride.

CONCLUSIONS

The evidence obtained by the integration of the different geophysical approaches have determined some important results: a) the data obtained with the two geophysical techniques show important elements of convergence and allowed to realize models of resistivity with a common interpretation criterion; b) the results obtained with HVSR measurements allowed to spread shallow information provided by ERT and MT, even outside the survey lines; c) the hydrogeophysical reconstruction of the study area allowed to identify local causes of the presence of high fluoride concentrations in groundwater; d) the overall geophysical framework is the starting point for the future integration with geological and hydrogeological information and for the realization of a 3D geological model.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690378.

References

Bauer P., Supper R., Zimmermann S., Kinzelbach W., 2006. Geoelectrical imaging of groundwater salinization in the Okavango Delta, Botswana, J. Appl. Geophys., 60(2), 126–141

Befus K.M., Cardenas M.B., Ong J.B., Zlotnik V., 2012. Classification and delineation of groundwater–lake interactions in the Nebraska Sand Hills (USA) using electrical resistivity patterns, Hydrogeol. J., 20(8), 1483–1495

Ghiglieri G., Da Pelo S., Pistis M., Melis M.T., Dessì F., Oggiano G., Abebe B., Azazegn T., Haile T., 2017. Geological and hydrogeological features controlling mechanisms of fluoride enrichment in groundwater in the East African Rift System. Proceeding - Flowpath 2017