Implementation of satellite-based data for improving predictions of arsenic contamination in groundwater in the Red River Delta in Vietnam

David Haaf [1, 2*], *Licia C. Pollicino* [3,4], *Stefania Stevenazzi* [3], *Marco Masetti* [3], *Son V. Nghiem* [5], *Michael Berg* [1], *Lenny H.E. Winkel* [1,2]

[1] *Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland.*
**Corresponding email: david.haaf@eawag.ch*

[2] *ETH Zurich, Institute of Biogeochemistry and Pollutant Dynamics, Zurich, Switzerland*

[3] *Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", Milano, Italy*

[4] *Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA), Milano, Italy*

[5] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA*

ABSTRACT

Natural arsenic contamination of groundwater aquifers is globally widespread, and particularly poses a problem in regions where groundwater is the main source of drinking and cooking water. Arsenic poisoning can lead to a myriad of serious health effects such as diseases of blood vessels, diabetes and cancers.

The aquifers of the Red River Delta in Vietnam are highly contaminated with arsenic and it has been estimated that in this area, around 3 million people are affected by high arsenic concentrations (> 10 µg/L, WHO guideline value; Winkel et al., 2011).

Previously, predictions of arsenic contamination in the Red River Delta were established via geospatial modelling using arsenic measurements, as well as surface and 3D-geology. Based on these predictions, probability maps of arsenic at specific depths were created. By comparing these depth-resolved probabilities to measured arsenic concentrations, a drawdown of arsenic-enriched waters from Holocene aquifers to previously uncontaminated Pleistocene aquifers was observed. This finding indicated that arsenic contamination has been exacerbated by excessive groundwater pumping rates (Winkel et al., 2011). Furthermore, in a study conducted in the Mekong delta, it was hypothesized that groundwater extraction causes interbedded clays to compact, thereby releasing water containing dissolved arsenic that is subsequently transported to deeper aquifers (Erban et al., 2013).

Such human-induced changes cannot be captured by the previous predictive models based on natural predictive parameters mentioned above, leading to erroneous predictions of the arsenic content in areas affected by urbanization, especially in deeper aquifers.

To improve predictions in human-affected regions we are using satellite data and remote sensing techniques that enable detection of changes of urban and suburban extents (Nghiem et al., 2009) and vertical build-up (Mathews et al., 2019). Those data and techniques in combination with geochemical and environmental data can help in i) resolving mechanisms behind arsenic mobilization in aquifers due to increased pumping rates and ii) making predictions of arsenic contamination more accurate, especially in areas characterized by increased groundwater pumping.

Keywords: groundwater, arsenic, geospatial modelling, pumping, urbanization

METHODS

To cope with this environmental issue, the Weights of Evidence Bayesian-based model can be considered a reliable methodology to gain a thorough comprehension of the spatial correlation between the occurrence of high arsenic concentration and factors potentially influencing deep aquifer contamination. The advantage of this modelling technique consists in the possibility of quantitatively defining the importance of chemical parameters and urban change patterns in controlling the deep aquifer susceptibility to arsenic pollution. These results have been achieved by analysing quantitative statistical parameters (weights, contrast) of each class by which each factor has been previously subdivided.

In addition to the chemical parameters observed in the Pleistocene aquifer (redox potential and iron concentration) the examined factors included: i) arsenic concentration in the Holocene aquifer and ii) satellite QuikSCAT (QSCAT) data processed with the innovative Dense Sampling Method (DSM; Nghiem et al., 2009) used to quantify urbanization in terms of building volume patterns and their rates of change in a decadal time span.

RESULTS

A direct correlation was found between arsenic contamination in the Pleistocene aquifer and: i) negative values of redox potential and ii) high iron concentration in the deep aquifer, iii) high arsenic concentration in the Holocene aquifer and iv) highly urbanized areas.

All these factors were combined to generate a predictive probability output, expressed as susceptibility map of the Pleistocene aquifer to arsenic contamination. The performance of this map was evaluated through the application of the same procedures adopted in previous groundwater vulnerability studies (e.g. Sorichetta et al., 2011).

CONCLUSIONS

The relationship between high arsenic concentration and chemical parameters detected in the deep aquifer has proved to be consistent with the outcomes derived from the analysis performed by Winkel et al., 2011.

The analysis on DSM data indicates that the excessive groundwater withdrawal, resulting from the high demand of water in intensive urban areas, has a strong impact on the quality deterioration of the Pleistocene aquifer. An extensive and excessive groundwater pumping can induce a vertical downward migration of chemical components leading to prevailing anoxic conditions and/or downward transport of arsenic contaminated waters from the shallow to the deep aquifer. Moreover, it could be the cause of the release of dissolved arsenic stored in deep interbedded clays into adjacent aquifers, suggesting clay-compaction as one of the factor affecting arsenic contamination in the deep aquifer. These results provide preliminary information on the nature of deep groundwater arsenic and on the sources responsible for its mobilization.

References

Winkel L.H.E et al., 2011. Arsenic pollution of groundwater in Vietnam exacerbated by deep aquifer exploitation for more than a century. Proc. Natl. Acad. Sci. USA. 108(4): pp. 1246-51

Erban L.E. et al., 2013. Release of arsenic to deep groundwater in the Mekong Delta, Vietnam, linked to pumping-induced land subsidence. Proc. Natl. Acad. Sci. USA. 110(34): pp. 13751-56

Mathews A.J., Frazier A.E., Nghiem S.V., Neumann G., Zhao Y., 2019. Satellite scatterometer estimation of urban built-up volume: Validation with airborne lidar data, Int. J. Appl. Earth Obs. Geoinformation, 77, 100–107, doi: 10.1016/j.jag.2019.01.004

Nghiem S.V. et al., 2009. Observations of urban and suburban environments with global satellite scatterometer data. ISPRS Journal of Photogrammetry and Remote Sensing. 64: pp. 367-380

Sorichetta A. et al., 2011. Reliability of groundwater vulnerability maps obtained through statistical methods. J. Environ. Manage. 92: pp. 1215–1224