

WATER POLICY BRIEF

Dynamic assessment of groundwater vulnerability for pollution at the African scale: A possible contribution to the monitoring of SDG 6

Issoufou Ouedraogo^{1,2}, Arthur Girard¹, François Jonard^{1,3}, Alice Alonso¹ and Marnik Vanclooster¹

1. Earth and Life Institute, Université Catholique de Louvain, Croix du Sud 2, Box 2, B-1348 Louvain-la-Neuve, Belgium
2. Ecole Supérieure d'Ingénieurs. Université de Fada N'Gourma, BP 54 Fada N'Gourma, Burkina Faso.
3. Forschungszentrum Jülich, IBG-3, Wilhelm-Johnen-Straße, 52428 Jülich, Germany

Contact: ouedraogo.issoufou03@gmail.com

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Groundwater Situation in Africa

Acknowledging the role of groundwater is paramount to successfully implementing the Sustainable Development Goals (SDGs) (Conti, 2016). With growing population, Africa needs more food and must secure the water and energy need to ensure its production at the same time as good quality water resources are becoming scarcer. Groundwater already does, and will increasingly play a crucial role in the fulfillment of the SDG for Africa and the African water vision towards poverty alleviation, socio-economic development, regional cooperation and environmental protection. Its role in supplying water services to communities is of strategic importance, with 75 percent of people served by groundwater for drinking (UNEP, 2010). Despite the strategic role of groundwater for livelihood support in Africa, it has remained a poorly understood and managed resource. As a result, African groundwater resources (GW) are increasingly exposed to overexploitation and contamination threats. This hampers sustainable groundwater service delivery and the meeting of the SDG6 on freshwater. Indeed, the proportion of the population having access to safe drinking water is one of the indicators for monitoring SDG6. Hence, the evaluation of this indicator for African countries strongly relies on data of the groundwater status. Yet the status of GW is difficult to assess, in particular with respect to water quality. Little is known about the spatial and temporal distribution of groundwater pollution at the continental scale in Africa. We addressed this significant knowledge gap about groundwater vulnerability to pollution in Africa by developing methods for assessing groundwater pollution risk at the African scale. Because, the dynamic behaviour of groundwater pollution could already serve as a guideline for planners and decision-makers. The presented risk mapping procedure allows contributing to the monitoring of SDG6 for African countries and deploying strategies that aim protecting drinking water resources.

Need for integrated management

Groundwater is a major component of available fresh water and it is an essential natural resource for overall development. In the hydrological system, groundwater is closely linked to surface water. The interconnections between surface waters and groundwater and human interactions with them call for an integrated management approach. Groundwater and surface water should, therefore, be managed coherently together in an integrated way. However, there are some inherent structural challenges related to such an approach. First, the areal extent of surface water basins and the underlying groundwater systems often differ radically (BGR and UNESCO, 2012), making groundwater management by river basin organizations complex. Second, given the subsurface nature of groundwater, data on groundwater status is often poor, in particular in many parts of the developing world like in Africa. There is, therefore, a need to improve the capacity of monitoring groundwater resources as a support for integrated water management of large river basins in Africa.

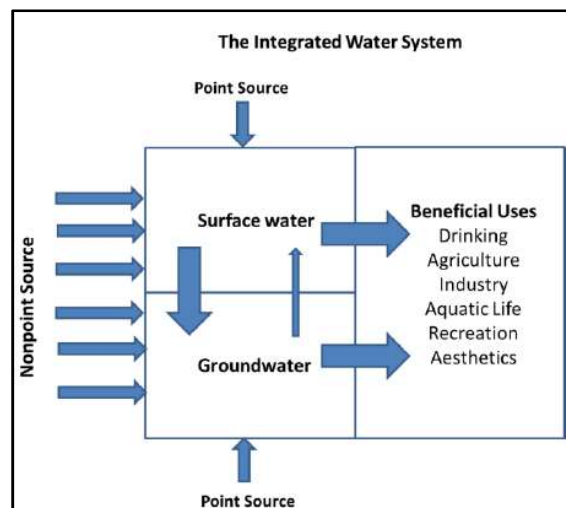


Figure 1: The interconnected water system. The blue arrows represent the inputs and flows of contaminants (Source: Calow et al. 2013).

Spatio-Temporal Groundwater Vulnerability to pollution Assessment: A contribution to the monitoring of SDG6

In a recent study that was financed by IDB and UCL (Ouedraogo, 2017), we designed methods allowing the time dynamic mapping of groundwater pollution risk at the continental scale. Using nitrate pollution as a proxy for groundwater

degradation, we identified key environmental factors that explain nitrate pollution in groundwater. The methods were partially validated using data collected from a meta-analysis. The vision of the study is to have an Africa where groundwater resources are valued, protected and utilized sustainably, and to empower stakeholders for the achievement of the UN SDG 6 by delivering operational methods for risk mapping of groundwater pollution.

Main findings

The following 3 key findings represent the outcomes of the study.

Key finding 1: Assessment groundwater vulnerability to pollution at the pan-African scale. We've mapped which aquifer systems/groundwater resources and settings are most vulnerable to pollution at the African scale. We showed clearly that groundwater resources in Africa are vulnerable and subject to pressures. Particularly, we shed the light on the pollution problem posed by shallow groundwater in Africa.

Key finding 2: By building a pan-African scale database of nitrate concentration through a meta-analysis of the available literature, we observed that nitrate concentrations average is 54.85 mg/L, with a wide range from 0 mg/l to 4625 mg/l, whereas the WHO threshold for drinking water is 50 mg/l. Using this database constructed, and by means of two statistical approaches, an unambiguous link was elucidated between population density (urban areas, agricultural activity) and pollution of groundwater by nitrates. In addition to the density of population, which is the top relevant variable found in both techniques, other factors affect the pollution of nitrate in groundwater. These comprise nitrogen fertiliser application and natural factors such as recharge, depth to groundwater, rainfall, and aquifer characteristics. Therefore, the study of the occurrence and transport of nitrate in groundwater requires acknowledgment of complex relationships among these different variables.

Key finding 3: We found that the groundwater vulnerability to pollution across Africa varies also considerably in time. In Figure 2, we observed that the spatial pattern of pollution risk at the pan-African scale has changed over the time between 1990, 2000, and 2010. For example, this variation was clearly observed in North Africa, in the Nile Delta, and in West Africa. The zone with the highest pollution risk at the scale of the continent is the Western Africa area, which is highly urbanized and densely populated. We found that the percent in pollution risk class of high and very high changed during 20 years from 0.55 % to 1.26 %; and from 0.29 % to 0.76 % respectively, which demonstrates that the surface of the risk of pollution follows an increasing trend (see Table). The absolute change in pollution risk is given in figure 3.

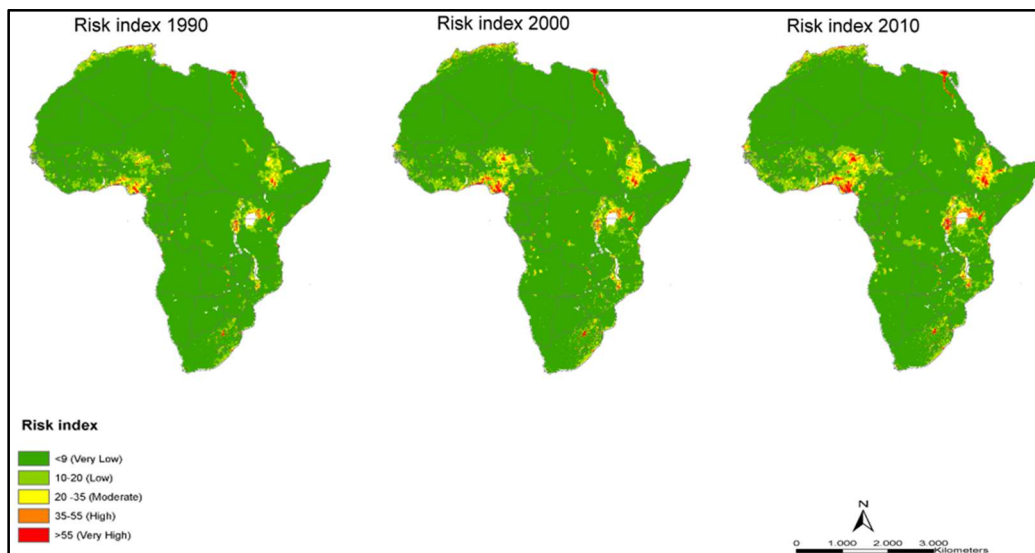


Figure 2: Groundwater pollution risk for 1990, 2000, and 2010

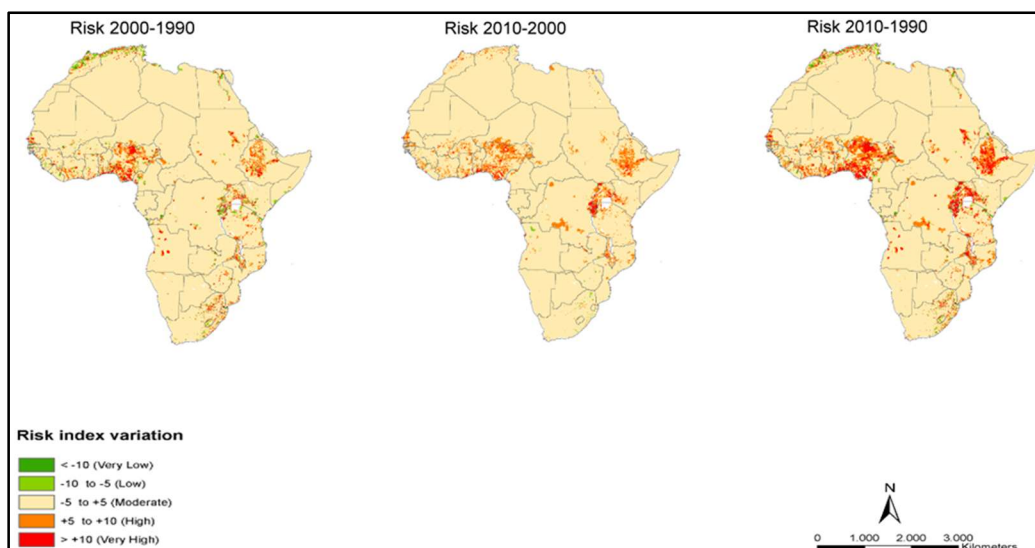


Figure 3: Absolute comparison of groundwater vulnerability for 1990, 2000, and 2010

Table: Percent of different pollution risk classes

| Year/period | Pollution risk class | | | | |
|-------------|----------------------|--------|----------|--------|-----------|
| | Very low | Low | Moderate | High | Very high |
| Year 1990 | 91.98 % | 5.5 % | 1.66 % | 0.55 % | 0.29 % |
| Year 2000 | 81.63 % | 6.49 % | 2.50 % | 0.87 % | 0.48 % |
| Year 2010 | 86.79 % | 7.94 % | 3.22 % | 1.26 % | 0.76 % |

Addressing the Challenges of Groundwater Quality: Science, Knowledge, and Capacity

As highlighted in the study, groundwater pollution problems are a growing threat to African continental development and urgently need to be addressed. The maps designed in this study show an interpretation of the groundwater resources map of Africa in terms of groundwater sensitivity and exposure to pollution. Because, until now, no general groundwater vulnerability map is available. To fill this existing gap, our study, we make an assessment of the vulnerability of groundwater at the pan-African scale. This study could help in many management domains.

Raising awareness: large-scale vulnerability maps could raise the awareness of policy makers and water managers about the vulnerability of this precious water resource system and increase the overall concern to develop appropriate protection programmes. It is also useful to scientists in government agencies and consulting companies.

Smart groundwater monitoring: Improving the assessment of water quality at a large-scale should be based on the appropriate monitoring. This assessment is needed to evaluate the compliance of different countries with overall political commitments, such as the commitment to reach sustainable water management in the WFD in Europe or to reach the SDG at the UN level. Hence, smart monitoring of water quality at a large scale is needed. We believe that smart monitoring of groundwater quality should be based on vulnerability. Monitoring should be concentrated primarily in areas that are vulnerable. Hence, vulnerability maps can help to optimise the smart large-scale monitoring programme. For example, recently in 2016, in the article *Accidental infrastructure for groundwater monitoring in Africa* published by Oxford University, the researchers tested the potential of using Africa's (Kenya as an example) accidental infrastructure to harmonise groundwater monitoring systems with rural water-security goals. They affirm that their study has the potential to be scaled up across Africa, meaning that every time water is pumped data could be harvested from the handle vibration help monitor Africa's groundwater resources. They say that smart hand pumps can help monitor Africa's groundwater resources.

In this respect, the groundwater vulnerability could serve as a good example for establishing a pan-African groundwater network like the strategies employed in Europe and the USA to establish large-scale groundwater monitoring networks and groundwater protection programmes. Groundwater protection and alleviation at the pan-African scale is not optional and acknowledging the role of groundwater is paramount to successfully implementing the SDGs. Remediation should be developed at both the continental and regional scale. The solutions that can be proposed to mitigate and improve the situation of groundwater quality issues have been partially addressed by Xu and Usher (2006):

- i. Political will: Groundwater quality protection is closely related to the government policy towards economic development and the political will for sustainable development and utilisation of resources. Our study may increase support for AMCOW (African Ministerial Council on Water) to proceed with groundwater protection programmes at the pan-African level. For example, the implementation of resolutions at the Pan-Africa Conference on Water (December 2003 in Addis-Ababa/Ethiopia) organized by AMCOW, are a good start for correct regulation of policies for the successful protection of water resources.
- ii. Capacity building and technical skills: Africa has little capacity to challenge groundwater degradation and there is a need to boost this capacity through appropriate capacity building programmes. As an example, capacity building can be increased by (a) the establishment of more formal networks of African universities working on water and sanitation; and (b) improving communication by increasing access to internet facilities.
- iii. Knowledge dissemination: Awareness of groundwater resources in Africa is low. There is a need to improve the knowledge of groundwater systems for decision-makers and for the broader public. This study may contribute to the increase of groundwater awareness. For example, in Africa, the number of technical people involved in groundwater studies is small.

In addition to these 3 main solutions above, which we recommend to decision-makers, we think that the African decision-makers for water resources must urgently elaborate groundwater protection programmes that are based on groundwater monitoring and data management. Such programmes can be boosted through a multilateral organisation such as the African Groundwater Commission or SADC, ECOWAS, the Nubian Aquifer Regional Information Systems (NARIS), The North Western Sahara Aquifer System (NWSAS) (better known under the acronym SASS for its French name "Système Aquifère du Sahara Septentrional"). Various institutions are working in many countries but they are scattered, isolated and uncoordinated. Groundwater management organisations should be created and connected with existing river basin organisations. Cooperation between neighboring countries is, therefore, a requirement if we are to reduce the risks of degradation and allow the sustainable use of these shared resources.

Also, groundwater monitoring in Africa needs to be addressed as a matter of priority. Based on the research conducted in this thesis, several factors for nitrate pollution have been highlighted. Of great concern is the fact that for many of these factors, the currently available datasets show that very little attention has been paid to the constituents in most groundwater monitoring programmes. Two sources of nitrate pollution are highlighted: urban areas and agricultural domains. High nitrate concentrations have been found to occur from sources ranging from agricultural fertilisers to pit latrines to explosives companies. There is no directed programme to monitor nitrate in urban and peri-urban areas and hence there is a gap in information.

The pan-African map is intended for continental or sub-regional (e.g. ECOWAS, SADC, IGAD region) use and has several limitations because it does not reflect local conditions. Each map type should only be used for the purpose for which it was produced (Vrba and Zaporozec, 1994). Areas of high risk on the map have a high potential for nitrate contamination but are not necessarily contaminated. A low vulnerability does not mean that there is no risk of contamination; it simply means that the geology and hydrogeology of the area provide more natural (or intrinsic) protection to the groundwater resources. Despite the issue of possible bias and uncertainties noted in the dataset collected for this dissertation, we are very optimistic about the robustness of the models for predicting contamination at the continental scale. The random forest machine learning model results presented in this research show that this is a promising technique for modelling groundwater degradation because of its ability to provide meaningful analysis of nonlinear and complex relationships such as those found in hydrogeological studies. The explained high variation of the random forest paves the way for creating water quality maps at the continent scale. Such maps are considered essential tools for developing groundwater management and development programmes, including transboundary groundwater management.

Notwithstanding some limitations related to data, the simple Dynamic Vulnerability Index (DVI) model allowed modelling the dynamic aspect of pollution risk at the pan-African scale using public available data. This is therefore an important tool for the sustainable groundwater resources management in Africa. The DVI could be used to monitor the achievement of SDG Goal 6 in Africa which includes a focus on preserving freshwater resources for potential future threats.

All methodologies presented in this study can be easily applied both to larger areas, and small areas, and used as a decision support tool for evaluation of legislative and management measures, aiming to reduce groundwater contamination risks. Although the present work was directed toward the vulnerability of groundwater to agricultural chemicals, of which nitrate was the exemplar, the methods developed in the course of this study are not specific to agricultural chemicals in groundwater. The same approach could easily be applied to other forms of pollution such as fluoride and arsenic.

Final comments

The results of the study have shed light on the pollution problem of groundwater at the pan-African scale. We demonstrated the unambiguous link between population density (urban areas, agricultural activity) and pollution of groundwater. In addition, the research highlighted that the groundwater vulnerability to pollution across Africa varies also considerably in time. We showed that the machine learning techniques are promising for modelling groundwater degradation at the African scale because of its ability to provide meaningful analysis of nonlinear and complex relationships such as those found in hydrogeological studies. This paves the way for creating water quality maps at the continent scale.

Works cited

- BGR, and UNESCO, (2012). River and Groundwater Basins of the World. (www.whymap.org).
- Calow, P., Snow, D., Bartelt-Hunt, S., Forbes, V. (2013). Challenges for Water Quality Policy in Nebraska: Short- and Long-Term. 8pp. <https://www.unomaha.edu/college-of-public-affairs-and-community-service/center-for-public-affairs-research/documents/policy-briefs/pb2013-water-quality-policy-in-nebrasa.pdf> (Accessed online August 21st 2017).
- Colchester, F. E., Marais, H. G., Thomson, P., Hope, R., & Clifton, D. A. (2017). Accidental infrastructure for groundwater monitoring in Africa. *Environmental Modelling & Software*, 91, 241-250. ISO 690
- Conti, K.I., Velis, M., Antoniou, A., Nijsten, G.J., (2016). Groundwater in the Context of the Sustainable Development Goals: Fundamental Policy Considerations. Brief for GSDR – 2016 Update. 5pp.
- Ippolito, A., Kattwinkel, M., Rasmussen, J. J., Schäfer, R. B., Fornaroli, R., and Liess, M. (2015). Modeling global distribution of agricultural insecticides in surface waters. *Environmental Pollution* 198: 54-60.
- Naumann, G., Barbosa, P., Garrote, L., Iglesias, A., and Vogt, J. (2014). Exploring drought vulnerability in Africa: an indicator based analysis to be used in early warning systems. *Hydrology and Earth System Sciences* 18(5): 1591-1604.
- UNEP, (2010). "Africa Water Atlas". Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi. Kenya.
- Vrba, J., and Zaporozec A., (1994). Guidebook on mapping groundwater vulnerability. International Association of Hydrogeologists, International Contributions to Hydrogeology, no. 16. Verlag Heinz Heise, Hannover.
- Xu, Y., and Usher, B. (2006). Groundwater pollution in Africa, Taylor&Francis/Balkema, The Netherlands. 353pp.