MARIE SKLODOWSKA-CURIE ACTIONS

Co-funding of regional, national and international programmes (COFUND)

DOC2AMU PROJECT 2018 CALL FOR APPLICATIONS

Hydro-economic modelling of the North western Saharan aquifer system

Key-words: transboundary groundwater resources, climatic and anthropogenic impacts, multi-agent economic model, hydro-economic model

1. DESCRIPTION OF THE PHD THESIS PROJECT

1.1 OBJECTIVES OF THE PROJECT BASED ON THE CURRENT STATE OF THE ART

This project is mainly related to the study of a scare resource, groundwater, in an area, the Sahara. These resources which exclusively support the oasis socio-economic systems are largely sensitive to climate change through precipitation-related groundwater recharge variations. But this aquifer is also noteworthy transboundary. Therefore, its regulation requires cooperation between the riparian countries.

Transboundary aquifers and groundwater depletion in the Saharan Area. The Maghreb region, especially the semi-arid to arid regions of the circum-Sahara area, is increasingly dependent on the use of non-renewable freshwater resources. Oasis socio-economic systems are sustained by massive deep transboundary aquifers that supply freshwater to the sedentary and nomadic populations. The North-Western Sahara Aquifer System (NWSAS), on which this project is focused, extends over Algeria, Tunisia and Libya and contains two aquifers: the deep Continental Intercalaire(CI), and the shallower Continental Terminal (CT). The present-day recharge does not equilibrate the abstractions whence the unsustainability of the resource. Despite the non-renewability of the resource, large amounts of water are extracted from these aquifers, primarily for agriculture. For instance, in the NWSAS, from 1970 to 2000, the withdrawals have increased from 0.6 to 2.5 km^3/yr for several boreholes which soared from 2000 to 9000. This extensive mining caused a piezometric level decline evidenced by the drying of springs (see e.g. Gonçalvès et al., 2015), the drawdowns in pumping wells (up to 100 m) or artesianism loss. For the CT aquifer that naturally feeds the oases from Tunisian and Algerian Chott area, the artesian discharge has dried up in many cases. This general lowering of water tables may irremediably destroy the fragile economy of these remote regions. For instance, in the areas where the aquifer is no longer artesian, pumping facilities (with extra costs) are required.

Implementation of a hydro-economic model (HEM) for the NWSAS. Although multidisciplinary issues are involved in such systems, geological and economic literatures have largely remained disconnected so far (see however, Chakravorty et al., 1995, about water conveyance). While the scientific and technical literature on hydrological behavior of large aquifer systems is extensive, relevant economic literature, especially on calibrated economic models, is rare. Most of the economic contributions remain rather theoretical. They simplify the aquifer behavior and address

specific issues like coordination failures, water quality issues, backstop questions induced by water storage or desalinization, markets for water rights. Moreover, these models often take the water demand as given. Therefore, a complete economic analysis should also propose an explicit derivation of the water demand especially for agricultural purpose.

Disconnecting hydrology and economics would restrict the scope and the relevance of this study. First, economic analysis needs a characterization of constraints e.g. natural factors that characterize the availability, the dynamics and sustainability of water resources to be relevant for real world policy advice. The absence of a HEM is a serious obstacle to optimal management of these aquifers. Investment projects can, for instance, be inadequate, either because they omit to exploit valuable resources, or because they overexploit them down to depletion and loss of artesianism. Secondly, understanding hydrodynamics of a reservoir does not ensure an optimal socio-economic resources exploitation. In particular, improvement of public policies dealing with aquifer resources seems to be necessary to have populations fully benefiting from technical hydrological progress. Finally, the reliability of future development plans (e.g., for irrigation purposes) that may be introduced, through extraction scenario, in hydrogeological models, omits the increasingly important contribution of economic factors such as behaviors of water users. But, socio-economic investigations of these Saharan ecosystems remain at this stage very scarce.

In this context developing a fully-coupled HEM is a desirable prospect. An integration of both economic and hydrological processes in a unique modeling platform will enable to explore the dynamics feedbacks between both components and pursue the objective of having a global model. This integrated approach also helps to explore various water management alternatives including regulatory instruments or overall optimization of the system (this is not possible with external coupling of models, e.g Harou, 2009). Lots of these approaches have been built on very simple economic or hydrogeological models that are not calibrated - thus not useful for decision making assistance-. We suggest developing a holistic calibrated HEM in GAMS (https://www.gams.com/) that connects a calibrated economic model (e.g. Graveline and Mérel, 2014) with a coarse grid hydrogeological model of the NWSAS derived by homogenization from a more refined and calibrated existing. This ensures that the behaviors of both components are representative of the real situation and opens the door to the study of various management options, especially in a multi-jurisdictional context since this aquifer is largely transboundary.

1.2 METHODOLOGY

A 3D regional groundwater flow model which reproduces the piezometric head distribution at steady state of the system considered in the reference year 1950 has already been built by the CEREGE group using the PMWIN (Modflow) model (Petersen, 2014). To take into account more accurately the anthropogenic effects of the 20th century, especially the increasing pumping rates starting at the beginning of the 1970's, the model will be updated. Specifically, we shall be able to determine when and where the aquifer system will no longer be artesian. These tasks will make possible to link the cost of extracting water to the piezometric head and will be incorporated in a complex global interaction model.

Several improvements can be introduced in the previous available PMWIN model. The introduction of storage coefficients already done for a paleorecharge reconstruction modeling (Petersen, 2014) has to be updated, pumping wells must be introduced and a calibration has to be made.

Subsequently to facilitate the coupling in GAMS, a simplified version of the model will be designed at a coarser resolution (semi-distributed unities will be considered to be homogeneous both from the hydrogeological and the water demand point of view). Its main objective will be to contribute to the calibrated hydro- economic model and to allow connecting the water demand and the corresponding pumping and policies evolution model to the simulation of the piezometric evolution of the aquifer at specific boreholes used to monitor its quantitative state. The simplified model, built in GAMS, will be based on a water balance including the main processes (recharge, storage, discharge) and transient forcings (climate, pumping) affecting the aquifer and the parameters values for the infiltration, storage and drainage will be taken from the distributed model. As stated above, its purpose will not be to simulate accurately the piezometric head distribution at steady and transient state on a regular grid, but rather to simulate it on geographically homogeneous areas from the water availability and management point of view.

The calibration which aims at reproducing observed drawdowns for the period 1970-2005 requires using all the available temporal records of hydraulic heads. Consequently, a precise data base for these piezometric head records will be needed. Thanks to the collaboration with OSS, the data base will take benefits of the GIS database implemented by OSS. Indeed, this precise database describes the borehole locations and related pumping rates. Once calibrated, the model will allow an efficient analysis of the consequences of alternative withdrawal scenarios on temporal evolutions of piezometric heads to be coupled with the economic modeling of task 3 (see below).

1.3 WORK PLAN

Task 1 concerns the building of a robust 3D hydrogeological model of the NWSAS to simulate time and space variations of the piezometric heads depending on abstraction and climate scenarios;

Task 2 is related to the characterization of the water demand. It describes the determinants of the decision of local households and farmers, mostly through their use of water in irrigated perimeters and constructs economic models of water demand. An investigation of the domestic and industrial uses of water in the studied area will be also carried out;

Task 3 will be dedicated to the coupling of the hydrogeological models (Task 2) and the economic model (Task 3) to form a calibrated hydro-economic model and a dynamic optimum hydro-economic model;

Task 4 of the project will represent the process of public decisions related to investment for water extraction and management. This is where the State strategies to deal with public good and externality problems, but also political issues, will appear. Although we shall base this module on publicly stated policies, we intend to provide analyses of these policies in terms of pursuit of rational objectives by public players. This also asks the question of the mechanism which implements these policy rules both inside a given country and between the different countries which benefit from the NWSAS.

Task 5 is specifically dedicated to the transfer of the developments proposed here to the end-users via the relevant resources management organizations namely the OSS.

	Year 1		Year 2		Year 3	
Task 1						
Task 2						
Task 3						
Task 4						
Task 5						

1.4 SUPERVISORS AND RESEARCH GROUPS DESCRIPTION

The project proposed here is part of the larger project SASHEM (Saharan Aquifer System Hydro-Economic Modeling) to be submitted to The EU program PRIMA (Partnership for Research and Innovation in the Mediterranean Area).

Julio Gonçalvès, CEREGE

CEREGE -Centre Européen de Recherche et d'Enseignement en Geoscience de l'Environnement- (http://www.cerege.fr/) is a Joint Research Unit founded in 1994 and set up by Université Aix-Marseille, CNRS, IRD and Collège de France. It comprises more than 130 researchers and engineers and about 25 PhD students. CEREGE is a leading research center on geosciences and environmental sciences. The "modeling" team of the CEREGE has an expertise based on available hydrological tools such as Modflow or own numerical developments when necessary for efficiency reason in the course of a research project. The thesis is in line with one of the height priority topics of CEREGE, the "Dynamique et Traçage des Hydrosystèmes" that is devoted to hydrology and numerical modeling of fluid flow and transport especially in arid and semi-arid regions. It is noteworthy that CEREGE members follow a long tradition in research on the African continent initiated by pioneer scientists (F. Gasse, M. Taïeb. R. Bonnefille among others) and has developed extensive experience of collaboration with African partners and field-trips in Sahel and Sahara.

Agnès Tomini, GREQAM

GREQAM -Groupement de Recherche en Economie Quantitative d'Aix-Marseille- (http://www.greqam.fr/)is a research unit in economics that is jointly managed by Aix-Marseille University, CNRS, EHESS and Ecole Centrale de Marseille. It comprises nearly 80 teaching and research staff and more than 75 PhD students. GREQAM has developed widely recognized skills in economics, with a department in environmental and natural resources economics. Moreover, GREQAM heads the labex Aix-Marseille School of Economics, dedicated to Globalization and Public action, with a focus on environmental issues. The environmental economists are also involved the

other multidisciplinary labex OT-Med, which is dedicated to the study of environmental issues in the Mediterranean region. Two environmental economists will be involved in the project: Hubert Stahn (University professor) and particularly Agnes Tomini (researcher at CNRS). Both develop theoretical models coupling economic objectives with hydrologic constraints.

2. 3I DIMENSIONS AND OTHER ASPECTS OF THE PROJECT

2.1 INTERDISCIPLINARY DIMENSION

The first supervisor will be Pr. Julio Gonçalvès, a specialist in hydrogeological modeling, who worked on the Sahara – Sahel region: i) recharge estimates of the NWSAS using GRACE solutions (Gonçalvès et al., 2013) and 36Cl (Petersen et al., 2014); Discharge quantification of the CI by a combined geostatistical and isotopic study (Gonçalvès et al., 2015) and iii) groundwater modeling of the NWSAS (PhD supervision of Petersen, 2014). The modeling expertise at CEREGE (Modflow, own numerical developments) will be mostly dedicated to the achievement of tasks 1 and 3.

The second supervisor will be Dr Agnès Tomini (CNRS), a economist who will be mainly supervising Tasks 2 to 4. She has been working for several years on groundwater economics and optimal management of natural resources. The strength of this partnership is the conjunction of theoretical economic skills with applied economics, both centered on water resource management.

2.2 INTERSECTORAL DIMENSION:

Operating in Africa's Sahara-Sahel region, OSS is an international, intergovernmental organization settled in 1992 that includes 22 African member countries, mainly devoted to the management of transboundary water resources (see http://www.oss-online.org/).

OSS will facilitate the achievement of task 2 concerning the building of the demand model. Therefore, The Socio-economic study carried out on behalf of OSS (Matoussi, 2014), for instance, which provides econometric data will be made available and is a fundamental pre-requisite for the success of the project. Data analysis and discussion with the authors of the study will necessitates several visiting stages at OSS (Tunis, Tunisia) for the doctoral candidate. The doctoral candidate will be also involved in task 5 described below on behalf of OSS.

To enhance dissemination of project results and to share as much information as possible, as widely as possible, within the region and beyond. Two workshops will be held during the last semester of the project in Algeria and in Tunisia. One will be dedicated to the main stakeholders of water resources at the local level such as farmers and farmers' associations directly and also research and development institutions at the local and regional levels. The second one is planned to be held back to back with a steering committee of the regional consultation mechanism. This mechanism, gathering representatives of Ministry in charge of water resources, is tasked with providing guidance towards the definition of a common vision and the design of the tools needed to ensure effective joint management of the shared water resource. It will be hence the opportunity to present the main outputs and outcomes of the project at a political level and to envisage their uses as decision making tools for national and regional agriculture strategy Interactions between the project coordinators (through OSS that host the Coordination Unit of the mechanism) will also be initiated at the beginning of the project.

2.2 INTERNATIONAL DIMENSION:

Increasingly awareness of the non-sustainability of these groundwater reservoirs has boosted the UN General Assembly to adopt resolution A/RES/63/124 fostering cooperation to ensure durable and peaceful management of these shared resources (Scheumann and Alker, 2009). This is one of the main missions of the Observatory of Sahara and Sahel (OSS). The sustainable socio-economic development of the region requires the implementation of scientific, technical and economic tools assisting decision-makers in making rational and informed choices between alternative policies (Scheumann and Alker, 2009). The construction of a relevant HEM is a part of this strategy. The aim is to assist stakeholders in the management of a transboundary aquifer system.

3.RECENT PUBLICATIONS

CEREGE

Gonçalvès J., Vallet-Coulomb C., Petersen J., Hamelin B. and Deschamps, P., (2015), Declining water budget in a deep regional aquifer assessed by geostatistical simulations of stable isotopes: case study of the Saharan "Continental Intercalaire". *J. of Hydrology,* 531, pp.821-829.

J.O. Petersen, P. Deschamps, J. Gonçalvès, B. Hamelin, J.L. Michelot, A. Guendouz, K. Zouari (2014) Quantifying paleorecharge in the Continental Intercalaire (CI) aquifer by a Monte-Carlo inversion approach of 36Cl data. *Applied Geochem.* 50,209-221.

Gonçalvès, J., Petersen, J. , Deschamps, P., Hamelin, B. and Baba-Sy, O (2013) Quantifying the modern recharge of the —fossil Sahara aquifers. *Geophys. Res. Letters*, 40, 2673–2678.

J.O. Petersen, P. Deschamps, B. Hamelin, J. Goncalves, J.-L. Michelot, K. Zouari (2013) Water-Rock Interaction and Residence Time of Groundwater Inferred by 234U/238U Disequilibria in the Tunisian Continental Intercalaire Aquifer System. Procedia Earth and Planetary Science, 7, 685-688

GREQAM

H. Stahn and A. Tomini, (2016)*On the Environmental Efficiency of Water Storage: The Case of a Conjunctive Use of Ground and Rainwater*Environmental Modeling & Assessment 21:691–706

H. Stahn and A. Tomini, (2015), *Rainwater harvesting under endogenous capacity storage: a solution to aquifer preservation?* Annals of Economics & Statistics, 119-120 : 209-234. 20

R Soubeyran,M. Tidball, A Tomini, K. Erdlenbruch, (2015)*Rainwater harvesting and groundwater conservation: When endogenous heterogenity matters*, Environmental & Resource Economics, 62 : 19-34.

A Tomini, (2014) *Is the Gisser-Sanchez model too simple to discuss the economic relevance of groundwater management?*, Water resources & Economics, 6: 18-29.

A Ayong Le Kamaand A. Tomini (2013) *Water conservation vs soil salinity*, Environmental Modeling & Assessment, 18(6) : 647-660.

4. EXPECTED PROFILE OF THE CANDIDATE

The candidate should be graduated in earth sciences with a specialization in hydrology or in economics with a specialisation in environmental and resources economics. In any case, the candidate should be familiar with applied mathematics and with the modelling tools of one of the previous specialisations. An experience with one or several programming languages is also desirable. The candidate will be involved in an interdisciplinary research project, he/she must therefore by enough curious and motivated to understand what is going on in the field which is not his/her initial specialization. In fact, during his/her PhD, the candidate should be able to contributes to both fields. Since this project also involves a transfer of knowledge, the candidate should have some skills to communicate his/her results not only to academics but also to local stakeholders.

5. SUPERVISORS' PROFILES

J. Gonçalvès (CEREGE)

Bief Curriculum Vitae

Goncalves Julio 17 may 1974, 43 years

goncalves@cerege.fr, CEREGE

●Since October 2010 Professor at Aix Marseille Université

●2003-2010 Assistant Professor at Paris 6 Univ. in Hydrogeology

Research interests: Groundwater hydrologist, numerical simulations of coupled flow and transport in porous media. Hydrodynamics of large sedimentary basins including the impact of the climatic signal in arid regions (Sahara and Sahel) on this functioning and groundwater recharge quantification.

Publications and metrix: 31 peer-reviewed papers and 1 Book chapter since 2002, h index & citations 10 & 450 (WoS) ; 13 & 680 (Google Scholar)

Relevant Thesis supervision:

-**Jade O. Petersen** "Traçage isotopique (36Cl, 4He, 234U) et modélisation hydrogéologique du Système Aquifère du Sahara Septentrional. Application à la recharge Quaternaire du Continental Intercalaire", **02/07/2014** AMU. Duration 4 yrs, 3 peer-reviewed papers, presently Post-doc at BGS, UK.

- **Camille Bouchez** "Bilan et dynamique des interactions rivière-lac(s)-aquifères dans le bassin hydrologique du lac Tchad", **10/07/2015** AMU. Duration 4 yrs, 2 peer-reviewed papers, presently Post-doc at Flinders Univ., Aus. **Louis Gentil- Jacques Bourcart price 2016 of the French Academy of Sciences for her PhD**.

-**one ongoing thesis** currently supervised (50% implication) started in 02/2014 will be defended this year.

A. Tomini (GREQAM)

Brief Curriculum Vitae

TOMINI Agnes 18 may 1980, 37 years

agnes.tomini@univ-amu.fr, GREQAM

● Since October 2014: CNRS research fellow at GREQAM.

● 2014: Research Assistant at LERNA (Toulouse) & GREQAM (Marseille).

● 2013: Post-doc fellow at Bren School of Environmental Science & Management (UCSB), Santa Barbara.

● 2011-12: Post-doc fellow at LAMETA-INRA (Montpellier).

● 2010-11: Post-doc fellow at LEM (Lille).

Research interests: Groundwater economics, optimal control and dynamic optimization, Natural resources in interaction, Public policies and public regulation of economic externalities.

Publications and metrix: 10 peer-reviewed papers (+3 others under revision) since 2009.

Head of master track: Health & Environment Economics (at Aix-Marseille School of Economics)

Cited References

Chakravorty, N., Hochman, E., Zilberman, D. (1995) A Spatial Model of Optimal Water Conveyance. *Journal of Environmental Economics and Management*, 29, pp. 25-41.

Gonçalvès J., Vallet-Coulomb C., Petersen J., Hamelin B. and Deschamps, P., (2015), Declining water budget in a deep regional aquifer assessed by geostatistical simulations of stable isotopes: case study of the Saharan "Continental Intercalaire". *J. of Hydrology,* 531, pp.821-829.

Gonçalvès, J., Petersen, J. , Deschamps, P., Hamelin, B. and Baba-Sy, O (2013) Quantifying the modern recharge of the —fossil|| Sahara aquifers. Geophys. Res. Letters, 40, 2673–2678.

Graveline, N., Mérel, P. Intensive and extensive margin adjustments to water scarcity in France's cereal belt. (2014) European Review of Agricultural Economics

Harou, JJ., Pulido-Velasquez, M., Rosenberg, D.E., Medellin-Azuara, J., Lund, J.R., and Howitt, R.E, (2009), Hydro- economic models: Concepts, design, applications, and futures prospects, journal of Hydrology, 375, p.627-643.

Matoussi, M.S., (2014), SASS III Aspects socio-économiques de l'irrigation dans le bassin du SASS rapport de l' OSS.

J.O. Petersen, P. Deschamps, J. Gonçalvès, B. Hamelin, J.L. Michelot, A. Guendouz, K. Zouari (2014) Quantifying paleorecharge in the Continental Intercalaire (CI) aquifer by a Monte-Carlo inversion approach of 36Cl data. *Applied Geochem.* 50,209-221.

J.O. Petersen (2014) Traçage isotopique (36Cl, 4He, 234U) et modélisation hydrogéologique du Système Aquifère du Sahara Septentrional. Application à la recharge Quaternaire du Continental Intercalaire. PhD Thesis, Aix-Marseille Université, Marseille, France.

Scheumann, W., Alker, M., 2009. Cooperation on Africa's transboundary aquifers- conceptual ideas. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques 54, 793-802.

AVIS DES DIRECTEURS DES LABORATOIRES CONCERNES PAR LE PROJET DE THESE

Avis du directeur du laboratoire du directeur de thèse, M. THOUVENY Nicolas

☒ Favorable ☐ Défavorable

Commentaires :

Fait à Marseille, le 19.12.17

Signature

NICOLAS THOUVENY

Directeur du CEREGE

Avis du directeur du laboratoire du co-directeur de thèse, M. VENDITTI Alain

☒ Favorable ☐ Défavorable

Commentaires :

Fait à Marseille, le

Signature

Alain VENDITTI

Directeur du GREGAM