Management Challenges and Opportunities in the Endorheic Basins of the Northern Saharan Transboundary Aquifers

C.M. King[1], M. I. Gad[2], B. B. Salem[3] and M. Ouessar[4]

(1) Oxford University Centre for the Environment, UK, email: caroline.king@ouce.ox.ac.uk
(2) Desert Research Center (DRC), Cairo, Egypt, email:drmohamedgad@yahoo.com
(3) University of Alexandria, Egypt, email: boshra.salem@dr.com
(4) Institut des Regions Arides, Tunisia, email: med.ouessar@ira.agrinet.tn

ABSTRACT

Reasonable utilization of land and water in transboundary aquifer systems requires consideration of the social and ecological dimensions of groundwater use. This paper discusses the experience of local institutions in monitoring and managing the changing groundwater conditions and utilization at the terminal outlets to two major North African transboundary aquifer systems, the Nubian Sandstone Aquifer System (NSAS) and the North West Sandstone Aquifer System (NWSAS).

Results from a multidisciplinary analysis of national research archives, remote sensing, interviews with decision-makers and direct surveys of cultivators in selected oases in both regions are used to examine the impacts of accelerated groundwater extraction from these systems during land reclamation and cultivation for both domestic and international agricultural export markets over the past two decades. Opportunities are identified for international initiatives to improve the management of the aquifer systems by encouraging the engagement of land and water users in local resource monitoring and management.

Key words: Nubian Sandstone Aquifer System (NSAS), North West Sandstone Aquifer System (NWSAS), adaptation to environmental change, groundwater vulnerability databases, management institutions

1. INTRODUCTION

Increasing aridity and climatic variability make groundwater the only reliable source of water for a growing number of land-users (WWAP 2009). At the same time, international demand for agricultural produce is exacerbating overextraction for irrigation (Giordano 2007). The management of transboundary aquifer systems requires thousands of individual land-users to recognize a shared responsibility, assess the effects of their actions, and manage the function of their land and water systems accordingly (Darnault 2008).

This paper draws on the findings of a multidisciplinary assessment of the impacts of environmental change over the past thirty years on groundwater resources in the geomorphological depressions of the North Western Desert of Egypt and the Chotts of the Nefzaoua region in Southern Tunisia. These land and water systems are situated at the terminal outlets of the two major North African transboundary aquifer systems, the Nubian Sandstone Aquifer System (NSAS), shared between Sudan, Chad, Libya and Egypt, and the North West Sandstone Aquifer System (NWSAS), shared between Algeria, Tunisia and Libya (CEDARE 2001, OSS 2003).

The paper begins with a brief review of the management objective of equitable and reasonable utilization, followed by an introduction of the selected land and water systems in the two transboundary aquifers and the changes taking place within them. Methods used to assess the impacts of global changes to groundwater resources are summarised. An overview of results obtained is presented in Section 4. Section 5 focuses on exploring best practices and lessons learned in local management data collection, and opportunities to strengthen collective management systems across the transboundary aquifers through international initiatives based on the findings from the two cases investigated.

2. CONCEPTUAL APPROACH

The UN Resolution (A/RES/63/124) calls on States to manage the `equitable and reasonable utilization` of transboundary aquifer systems. `Equitable and reasonable` utilization is defined in relation to a series of social and ecological factors. In arid environments, where populations depend on groundwater, considerable challenges are apparent in terms of understanding the changing condition and functions of the surrounding socio-ecological systems (Safriel et al. 2005). These information needs are the subject of global efforts to improve the monitoring of land degradation and Sustainable Land Management (SLM).

Challenges encountered at the national level in monitoring groundwater use by both large and small users have led to growing emphasis on the role of socio-ecological or participatory local management approaches (Khater 2003, MWRI 2005, Shah 2005, van Steenbergen 2006, Darnault 2008). These approaches often seek to apply the principles of common pool resource management to address the groundwater management challenge (Ostrom 1990, Pahl-Wostl 2009, Shah 2009). Sharing of information to establish mutual trust and accountability is seen as central to this process (IBRD 2007). This is difficult to achieve where institutions are very decentralized or informal, and without channels for collecting, analyzing and disseminating local management information (Hammani et al. 2009).

Over recent years, international efforts to monitor SLM have explored options to integrate State-led monitoring processes with land-users observations, knowledge and actions. This experience has generated new approaches to monitoring and managing land and water systems where cultivators are depending on transboundary aquifers. Such approaches are investigated in this paper through local scale assessments of groundwater conditions and use within the two transboundary systems.

3. LAND AND WATER USE SYSTEMS CONTEXT AND INVESTIGATION METHODS

The Nefzaoua region is located at the terminal point of the NWSAS, while the Northern Oases of the Western Desert, Siwa and Wadi El Natrun, are underlain by the NSAS. Variable salinity is a natural condition of aquifers in both systems Both the NWSAS and NSAS receive minimal recharge in comparison to extraction, and reserves of fossil water in these deeper aquifers are considered non-renewable (Mamou 1990, CEDARE 2001, OSS 2003). Both regions have supported cultivation for several millennia. Use of naturally emerging spring water and locally recharged drainage water in the local phreatic aquifers does no harm to the transboundary aquifer systems that feed them, or to their associated ecosystems. Indeed, as the soil quality and microclimate are adjusted by the presence of vegetation, the efficiency of water storage and use at the surface increases. This utilization may therefore be considered reasonable according to A/RES/63/124.

Over the past three decades, the number of wells in use in both systems has increased exponentially (Khater 2003, Ould Babasy 2005). While the early wells tapped the overlying local aquifers, land and water management practices have led to the depletion and contamination these shallow renewable sources. Since the 1990s, the middle aquifers at depths of around 100m (the Complex Terminal in the NSAS and the Miocene layers at in the NSAS) have become overexploited, forcing new wells to be drilled deeper into the underlying layers. The Continental Intercalaire (CI) in the NSAS is around 800–2,500m below the Nefzaoua region, and the freshwater Cretaceous layer of the NSAS is at depths of around 1000m beneath the Northern part of the Western Desert.

National research libraries and management databases were used to investigate land and water development patterns in both regions. ERDAS Imagine™ software was used to analyze the Normalized Difference Vegetation Index in multiple Landsat images provided by the USGS in order to detect changes in extent of vegetation cover due to increasing use of groundwater for irrigation. In each location, surveys of cultivators were used to further interrogate these changes, and local efforts to manage the degradation of the land and groundwater resources.

4. RESULTS

4.1. Impacts of changing land uses on groundwater resources

In 1987, Landsat images showed an area of high NDVI covering 10,942 hectares in the Nefzaoua region and a combined total of 6,970 hectares in the two North Western Desert locations of Siwa and Wadi Natrun. By 2003, the Nefzaoua area had undergone a 44% expansion to 15,796 hectares. In the Western Desert areas, a 153% expansion took place. In both cases, the increase can be attributed to the expansion of ground-water irrigation, of which, a significant portion is believed to be unauthorized. In the Tunisian case, decision-makers estimated the level of illicit extractions at around 30% of the total following an investigative field survey (Siegfried 2004). Both official extraction figures and remotely sensed data have continued to show increases in the rates of ground water extraction and the extent of the vegetated area over subsequent years until 2010.

Falling water tables and loss of artesian pressure have been observed in both regions (see eg Mamou and Hlaimi 1999, Khater 2003). These observations were confirmed by groundwater users interviewed during field investigations. As water tables have fallen, the costs for pumping water have risen. Small landholders surveyed either use deep wells provided by the government, or unauthorized shallow wells that remain vulnerable to contamination. In Egypt, electric pumping systems used by large landholders holding permits for groundwater extraction have become cheaper than the diesel pumps used by smaller and informal landusers although their groundwater use is renewable.

Local monitoring over the past decade has shown Total Dissolved Solids rising to above 8g/l in the most exploited parts of the NSAS Complexe Terminal aquifer and to comparable levels in parts of the NSAS (Hossary 1999, Attia et al. 2007). In addition to salinization of aquifers, irrigation causes secondary salinization and sodicity problems where poor drainage leads to waterlogging eg at Siwa in the Western Desert and in low lying areas around the Chott El Djerid in Nefzaoua. Salt deposits on the soil surface can affect surface recharge (Kadri 2002, El Fahem 2003, Gad and Abdel-Baki 2002). Regional models have predicted increasing salinization threats (Zammouri 2007, Attia et al. 2007).

4.2. Responses of land users to changing groundwater conditions

Cultivators in both regions observed the effects of increasing water scarcity and rising salinity on their crops. The two problems interact because salinity weakens the ability of the plants to take up water, making them more prone to water stress and disease. Cultivators adapt their water use and cultivation patterns to cope with productivity losses, either reducing investments in land improvement and cultivation where they will bring diminishing returns, or digging deeper wells to bypass the trend in groundwater degradation. Digging deeper wells solves the immediate problem for individual cultivators, but further exacerbates the threats to the common pool resource, and decreases the overall resilience of the production systems. Both of these outcomes from land users` responses to changing groundwater conditions threaten the function of the cultivated ecosystems and the benefits that they provide to dependent populations. Groundwater uses leading to these outcomes might therefore not be considered reasonable and equitable, as defined in A/RES/63/124.

Different approaches to collective groundwater management associations have been pursued in the two countries. In the case of the Western Desert, where water user associations remain informal, when new wells have been installed either by the State, or increasingly by private water users, the traditional associations have weakened or disappeared altogether. In Tunisia, water user associations are supported by the State, and continue to provide timed water allocations to small cultivators. But these systems are still more vulnerable to water scarcity and degradation than those who have their own private wells. They are therefore considered less efficient in terms of water-productivity than private agricultural producers, which operate outside the collective management associations. In neither case do the water user associations include all groundwater users, nor do they have sufficient capacity to generate effective management data on the shared resource.

5. DISCUSSION:

5.1. The institutional challenge of monitoring and managing the aquifer system's response

Available public data indicates groundwater degradation trends in both regions, but remains incomplete. Public monitoring programmes in Egypt cover a wider area at a relatively coarse resolution when compared to Tunisian groundwater monitoring (DGRE 1979-2006, EEAA 2009). As demonstrated in the previous section, comparable estimates of increases in the irrigated area in the two regions can be generated from remote sensing of NDVI. However, irrigated areas where crops are at early growth stages or have undergone degradation are under-detected using these methods. Nor do they take into consideration groundwater extraction for non-agricultural uses.

Accurate quantitative data on groundwater use by private companies is not available, nor do such companies share hydrogeological information, since this has become a determining factor in the competitiveness of drilling companies, water providers and agricultural export corporations. This constrains the availability of data for management use. States are required to establish expensive parallel data collection infrastructures when a wealth of information already exists in private databases. Regulation through permit systems has taken time to establish, due to the large number of pre-existing unregistered wells and the high transaction costs of controlling use (see Kassah 1996, Khater 2003).

5.2. Best practices in monitoring equitable and reasonable utilization

Groundwater managers interviewed in Egypt indicated that the integration of regulatory systems for land registration with the groundwater permit system was providing increasingly effective incentives for landusers to register their wells. Registration requires users to provide documentation on the hydrogeological conditions. The resulting database is then maintained by the State to enable analysis of the evolving groundwater management situation. This does not address the problem of pre-existing and new unauthorized wells. However, it represents a promising step forward.

Field survey and rapid appraisal techniques directly engaging land-users have been used efficiently to complement official groundwater monitoring statistics in the Nefzaoua region. Further contributions have been made through this investigation, and other local activities by researchers in the field of Sustainable Land Management, generating valuable information concerning the management of groundwater and other inputs by landusers (eg Meddeb 2003, Siegfried 2004, Hammani et al. 2009). In the NSAS, on the other hand, the connection of groundwater management assessments to socioeconomic databases has been explored on a larger regional scale (eg Attia 2002).

5.3 Opportunities to improve management through information sharing

The increasing economic value of groundwater used for high value agricultural exports from both regions could enable improved investments in groundwater management systems, with increased support from the private sector. Whereas, at present, the larger companies run private laboratories in order to analyze the quality of their produce, soil and water supplies, these facilities and data could be used to complement the limited public monitoring systems. While States must coordinate their own institutions for collective management and monitoring, international processes could move this agenda forward more rapidly by requiring data sharing and socially responsible contributions by the larger export corporations to enhance local and transboundary resource management. One new entry point may be through the international environmental certification systems for agricultural export.

Refinements to water use estimates are still needed in order to take into account the efficiency of water uses under different technologies, at different salinities and from different sources – deep, shallow or recycled. For all of these, resource-user information to inform regional scale assessments requires effective processes for local sampling. As described above, the socioeconomic dimensions of groundwater use can be addressed at the local level through SLM surveys and participatory assessments, and at the regional level through connection to national census data. There is an opportunity to meaningfully integrate these different scales of socioeconomic data and to overcome sectoral barriers within ongoing assessments of transboundary aquifer management.

6. CONCLUSIONS

Accelerated groundwater extraction over the past three decades in the Northern Sahara has supported agricultural land reclamation for both domestic and export markets. Sometimes the groundwater use has succeeded in creating benefits and increased productivity. However, there have also been less reasonable and indeed harmful uses where misapplication of technologies and lack of understanding of ecological conditions has led to the depletion and contamination of the transboundary aquifer systems and degradation of productive land.

Best practices in information sharing to better understand and manage the reasonable and equitable use of groundwater dependent ecosystems in the Northern Sahara demonstrate scope for ongoing management improvements. Interactions between monitoring initiatives focusing on groundwater management and Sustainable Land Management more broadly are few at the international level, and at the practical level they are equally rare. International attention to this gap could enable a timely response to global change processes affecting transboundary aquifer systems and the people who depend on them.

Acknowledgements

This paper draws on the findings of a Doctoral research project at the Oxford University Center for the Environment in cooperation with the Institut des Regions Arides, Tunisia, and the University of Alexandria. The research was supported by ESRC/NERC. A portion of the fieldwork was carried out in cooperation with the UNU-UNESCO joint research project on Groundwater and Human Security Case Studies (GWAHS-CS). The Egyptian Desert Research Center, Groundwater Research Institute, the Tunisian Ministry of Agriculture and Water Resources and Commission Regional de Developpement Agricole of Kebili, amongst other institutions, provided essential archived information and advice enabling the study to be completed.

REFERENCES

Attia, F. A. R. 2002. The Nubian Sandstone Aquifer System Program Basic Information of the Socio-economic Survey. In *NSAS Socioeconomic Survey*, 94.

Attia, F. A. R., H. Fahmy, M. Eid, J. H. (ed.) & R. Slootweg. 2007. The West Delta Water Conservation and Irrigation Rehabilitation Project (WDWCIRP) Environmental and Social Impacts and a Framework Management - Plan Part I: Environmental and Social Impact Assessment, Part II: Environmental and Social Management Plan - final draft. 86. Arab Republic of Egypt Ministry of Water Resources and Irrigation and World Bank.

CEDARE. 2001. Regional strategy for the utilization of the Nubian Sandstone Aquifer System (groundwater model). . Cairo: Center for the Environment and Development for the Arab Region and Europe.

Darnault, C. 2008. Overexploitation and Contamination of Shared Groundwater Resources Management, (Bio)Technological, and Political Approaches to Avoid Conflicts. In *NATO Science for Peace and Security Series C: Environmental Security*. Dordrecht, Netherlands: Springer.

DGRE. 1979-2006. Annuaire de l'exploitation des nappes profondes. Tunis: Direction Generale des Ressources en Eau.

EEAA. 2009. Egypt State of Environment Report 2008. 360. Cairo: Ministry of State for Environmental Affairs (MSEA), Egyptian Environmental Affairs Agency (EEAA)

El Fahem, T. 2003. Salinization of Groundwater in the Nefzaoua Oasis - South Tunisia. In *Geology*, 121. Aachen: Aachen University.

Gad, M. I. M. & A. A. Abdel-Baki. 2002. Estimation of Salt Balance in the Soil-Water of the Old Cultivated Lands in Siwa Oasis, Western Desert, Egypt. In *Proceedings of the International Symposium on Optimum Resources Utilization in Salt-Affected Ecosystems in Arid and Semi-Arid Regions,* ed. DRC, 16-23. 8-11 April, 2002, Cairo, Egypt: MALR.

Giordano, M., and K. Villholth, eds. . 2007. The Agricultural Groundwater Revolution: Opportunities and Threats to Development. In *Comprehensive Assessments of Water Management in Agriculture No 3.* Colombo: International Water Management Institute and CABI.

Hammani, A., T. Hartani, M. Kuper & A. Imache (2009) Paving the way for groundwater management: Transforming information for crafting management rules *Irrigation and Drainage,* 58**,** 240-251.

Hossary, M. F. M. E. 1999. Evaluation and Management of Groundwater Resources in Siwa Area with Emphasis on the Nubia Sandstone Aquifer. In *Geology Department*, 138. Cairo: Ain Shams University

IBRD. 2007. Making the most of scarcity : accountability for better water management results in the Middle East and North Africa. In *MENA development report on water,* ed. W. Bank, 270. Washington D.C.: World Bank.

Kadri, A. (2002) Contraintes de la production oasienne et strategies pour un developpement durable Cas des oasis du Nefzaoua (Sud Tunisien). *Secheresse,* 13.

Kassah, A. (1996) Les politiques d'amenagement hydro-agricole au Sahara Maghrebin: Approche comparee. *Revue des Regions Arides,* Numero special: Actes du seminaire international**,** 396-401.

Khater, A. R. 2003. Intensive groundwater use in the Middle East and North Africa. In *Intensive use of groundwater: challenges and opportunities,* eds. R. Llamas, E. Custodio, C. Coleto, A. Huerga & L. M. Cortina, 355-386. Lisse, Abingdon Balkema.

Mamou, A. 1990. Caractéristics et évaluation des ressources en eau du sud Tunisien [Characteristics and evaluation of the water resources in southern Tunisia]. . Paris: Université du Paris-Sud Centre d'Orsay.

Mamou, A. & A. Hlaimi. 1999. Les nappes phréatiques de la Nefzaoua. Tunis: Direction Générale des Ressources en Eau. Ministère de l'Agriculture.

Meddeb, M.-F. 2003. Field Investigation in the Sustainable Production of the Nefzaoua Oases. In *Department of Geology*, 81. Goteborg, Sweden: Chalmers University of Technology.

MWRI. 2005. Participatory Water Management in the Egyptian Oases 30. Cairo: Ministry of Water Resources and Irrigation.

OSS. 2003. The North West Sahara aquifer system: joint management of a transborder basin. 142. Tunis: Observatoire du Sahara et du Sahel (OSS).

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge: Cambridge University Press.

Ould Babasy, M. 2005. Recharge et Paleorecharge du Systeme Aquifere du Sahara Septentrional. In *Faculte des Sciences de Tunis, Departement de Geologie*, 271. Tunis: Universite de Tunis El Manar.

Pahl-Wostl, C. (2009) A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change,* 19**,** 354-365.

Safriel, U., Z. Adeel, D. Niemeijer, J. Puigdefabregas, R. White, R. Lal, M. Winslow, J. Ziedler, S. Prince, E. Archer, C. King, B. Shapiro, K. Wessels, T. Nielsen, B. Portnov, I. Reshef, J. Thonell, E. Lachman & D. McNab. 2005. Dryland Systems. In *Current State and Trends*, 623-662. Island Press: Millennium Ecosystem Assessment.

Shah, T. (2005) Groundwater and human development: Challenges and opportunities in livelihoods and environment *Water Science and Technology* 51**,** 27-37

---. 2009. *Taming the Anarchy: groundwater governance in South Asia*. Washington DC: Resources for the Future.

Siegfried, T. U. 2004. Optimal Utilization of a Non-Renewable Transboundary Groundwater Resource Methodology, Case Study and Policy Implications. 131. Zurich: Swiss Federal Institute of Technology.

van Steenbergen, F. (2006) Promoting local management in groundwater. *Hydrogeology Journal,* 14**,** 380-391.

WWAP. 2009. The 3rd United Nations World Water Development Report: Water in a Changing World (WWDR-3). 318. Paris and London: UNESCO Publishing.

Zammouri, M., Siegfried, T., El-Fahem, T., Kâa, S., Kinzelbach, W. (2007) Salinization of groundwater in the Nefzawa oases region, Tunisia: Results of a regional-scale hydrogeologic approach. *Hydrogeology Journal* 15**,** 1357-1375.