Transboundary Groundwater Management Issues in the Nubian Sandstone Aquifer System (NSAS)

Caroline King-Okumu and Ahmed Abdelkhalek

Abstract Transboundary resource management refers to the principle of reasonable utilisation of land and water. This requires consideration of the social and ecological dimensions of groundwater use, in addition to hydrological monitoring and modelling systems. Egypt is a world leader in transboundary groundwater management and regional cooperation on water management issues more broadly. This chapter discusses Egypt's experiences in leading knowledge generation and sharing with other riparian countries to further the sustainable utilization of the major transboundary aquifer in Africa: the Nubian Sandstone Aquifer System (NSAS). To date, Egyptian transboundary groundwater management initiatives have been state-led, and have focused on the generation of studies with the intent to share data between countries on the hydrological conditions and volumes of water flowing through the aquifer. This is intended to enhance management and coordination. However, this data sharing is slow and sometimes sensitive. Furthermore, it has been difficult for the transboundary groundwater management initiatives to get to grips in any practical way with the challenges of sustainable groundwater use. Practices to conserve the health of the land that stores the groundwater reserves, and enable their replenishment also receive little attention in transboundary cooperation for groundwater management. To monitor, manage and sustain the hydrological, ecological and socioeconomic aspects of the transboundary system requires the engagement of local institutions to conduct or facilitate the monitoring and to implement the management practices. For them, it is important not only to pursue the sustainable management of the aquifer over the longer term, but also to consider how to improve the viability of local resource management in the short term. In light of this, the main recommendation is to build and share knowledge about local capacities to manage ecosystem

C. King-Okumu (✉)
The Borders Institute (TBI), Africa, Nairobi, Kenya
e-mail: caroking@yahoo.com

GeoData Institute, University of Southampton, Southampton, UK

A. Abdelkhalek
Technical Office of Groundwater Sector, Ministry of Water Resources and Irrigation, Giza, Egypt
e-mail: ahmedimail@yahoo.com

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service production and recharge patterns in the surface layers, as well as to monitor and jointly manage the reserves stored in the deeper layers.

Keywords Transboundary · Nubian sandstone aquifer system · Sustainable management · Egypt

Introduction

Transboundary resource management refers to the principle of reasonable utilisation of land and water [1]. This requires consideration of the social and ecological dimensions of groundwater use [explored in 2], in addition to hydrological monitoring and modelling systems. Egypt is a world leader in transboundary groundwater management and regional cooperation on water management issues more broadly. This chapter discusses Egypt's experiences in leading knowledge generation and sharing with other riparian countries to further the sustainable utilization of the major transboundary aquifer in Africa: the Nubian Sandstone Aquifer System (NSAS).

The main of objective of the chapter is to explore how Egypt can lead the way forward toward the sustainable utilization of the NSAS. Egypt is doing this by sharing insights with the other riparian countries concerning available management technologies and innovations as it pushes the boundaries of science, engineering and ecosystem management to respond to pressing shared water management challenges.

The remainder of the introduction to this chapter provides an overview of the NSAS and the growing sustainability challenges as they are currently experienced in Egypt. Section 2 then discusses the principles of sustainable utilization of groundwater in transboundary systems. In the third part of the chapter, a brief overview of transboundary cooperation in the NSAS is provided. The fourth part is devoted to discussion of the challenges and way forward. Finally, some conclusions and recommendations are offered.

Overview of the Nubian Sandstone Aquifer System (NSAS) and Its Sustainability Challenge

Egypt receives transboundary flows of groundwater through the Nile Basin and also through the Nubian Sandstone Aquifer System (NSAS). The NSAS has been described by Nijsten, Christelis [3] as the 'heavyweight' amongst all of the transboundary aquifer systems in Africa and the largest known fossil aquifer in the world. This is due to its extent—underlying some 2,500,000 km^2 of Egypt, Libya, Chad and Sudan, and to the estimated volume of non-recharging water reserves that it contains [4] (see Fig. 1). The countries sharing the aquifer system include: Sudan, with approximately (17%) (373,000 km^2 located in the north-western part of the country; Chad, with about 11% (around 233,000 km^2 located in the north-eastern part of the country;

Fig. 1 Extent of the Nubian Sandstone Aquifer System according to the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System (JASD-NSAS). *Source* Ahmed Abdelkhalek, based on: [4] and https://www.nsasja.org/domain_en.php

Libya, where about 37.5% of the aquifer covers around 754,000 km^2 of south-eastern Libya; Egypt, which receives the remainder, underlying around 816,000 km^2 [5]. The results of a very large-scale GIS-based groundwater flow model for the NSAS in the Eastern Sahara (Egypt, north Sudan and east Libya) indicated that the groundwater in this aquifer was formed by infiltration during the wet periods 20,000 and 5,000 years b.p. The recharge of groundwater due to regional groundwater flow from more humid areas in the south was excluded. It also indicates that the NSAS is a fossil aquifer, which had been in unsteady state conditions for the last 3,000 years [5–8].

According to the latest estimates [9], the total volume of fresh groundwater in storage in the NSAS is around 372, 950 billion cubic metres (BCM) of which 41.5% (154,715 BCM) is in Egypt, 36.6% (136,550 BCM) in Libya, 12.8% (47,807 BCM) in Chad, and 9.1% (33,878 BCM) in Sudan. However, the bulk of this water is either too deep to reach and abstract with the present techniques, or too salty to use, particularly in the northern areas. Therefore, only about 3.9% of the reserve (14,459 BCM) is recoverable at the present.

NSAS has two aquifers; the most important is the Nubian Aquifer System (NAS) which is located underneath the Post Nubian Aquifer (PNA) (see Fig. 2). Low permeability layers are located between these two aquifers. PNA is an unconfined aquifer located only in the northern region of NSAS and is used by Egypt and Libya. NAS covers the whole area of NSAS and is used by all four countries. Although NAS is unconfined in the south of NSAS, it is confined in the northern region due to the presence of PNA [6]. Across Egypt's Western Desert, the NSAS is overlain by other more recent aquifers, which do receive recharge water vertically and horizontally, as well as being fed from the NSAS below [10, 11].

NSAS contains a large amount of groundwater amounting to about 475,753 km^3 assuming storativity values of the confined and unconfined aquifers to be 104 and 7,102, respectively. However, only a small portion of this volume can actually be developed due to deep depths to groundwater and the corresponding high pumping costs [12, 13]. Bakhbakhi [12] calculated the total recoverable groundwater in each country assuming maximum water declines in unconfined and confined aquifers are 100 m and 200 m, respectively. The result found that the total recoverable groundwater in Egypt to be 5,367 km^3 and the extraction at that time was only 0.506 km^3/year, indicating the availability of a large volume of unused water [12]. Contemporary management strategies for sustainable use of the multi-layered aquifer system should consider the integrated management of both the renewable and non-renewable aspects in different locations and contexts. For ongoing and future development potential in Libya, Salem and Pallas [14] have observed that the Post Nubian reservoir corresponding to the Post Eocene deposits in Egypt and Libya are also more important than the older Palaeozoic and Mesozoic deposits that extend over the whole Nubian Basin. This is partly because the Nubian System itself becomes very saline in the northern part in Egypt and Libya.

In Libya, the "Great River" the Man-made River began extracting substantial amounts of water from this aquifer By the end of the twentieth century [15]. The Libyan "Great River" is the Manmade piping system in the Sahara Desert of Libya as huge network of pipes to supply water from the Nubian Sandstone Aquifer. It is

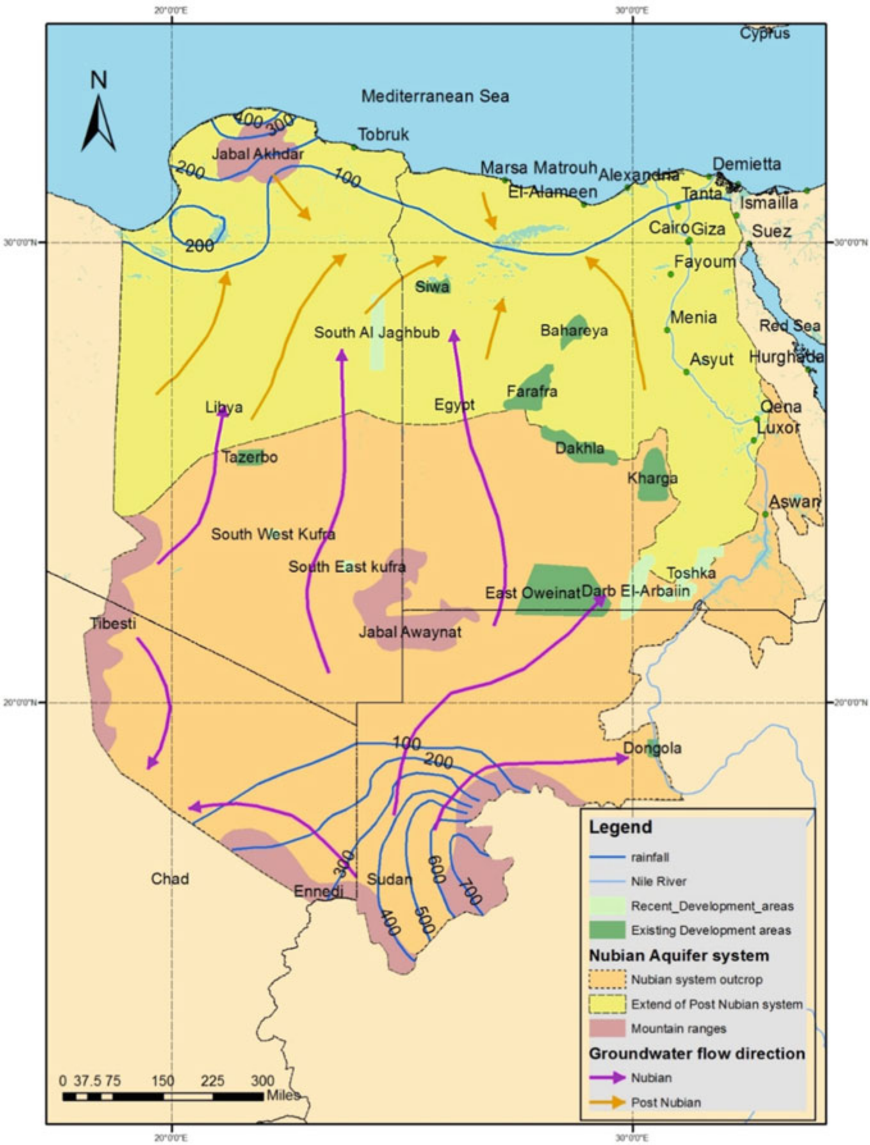

Fig. 2 Map of major flows and features in the Nubian Sandstone Aquifer. *Source* Ahmed Abdelkhalek, based on [4] and https://www.internationalwaterlaw.org/blog/2013/10/20/adoption-of-regional-strategic-action-plan-on-the-nubian-sandstone-aquifer/

the world's largest irrigation project. The extraction is estimated 2.37 km^3 per year. The extracted water is primarily used to supply the Kufra Oasis with water [16].

In Egypt, groundwater of the NSAS is the backbone for the development in the Western Desert, where it represents the sole source for water supply [16]. Interestingly, as the development of water resource management and use is evolving in Egyptian parts of the NSAS, the dynamic renewable aspects of the aquifer system are transforming and growing rapidly. The Use of NSAS in the Western Desert region of Egypt started in in the early 1960s in an effort to increase agricultural productivity. Groundwater withdrawal was initiated at five locations; Kharga, Dakhla, Farafra, Bahariya, and Siwa Oases for both agricultural and domestic uses. In 1990, a new agricultural area was developed using groundwater from East Oweinat [15, 17].

In 2015, a new national project to reclaim 1.5 million Feddan was initiated for the reclamation of lands in about 15 different locations in Egypt, most of them are located in the Western Desert region due to the large volume of groundwater available from NSAS (see the Chapter authored by Abdelkhalek and King in this book). In addition to this, a canal system has been constructed along the northern edge of the Western Desert (Al Hamam canal extension), bringing in additional supplies of water to the former marginal rangeland areas. A series of desalination plants have also been constructed along the Northern coast to supply drinking water to expanding coastal settlements (personal communication, Cairo Water Week, http://www.cairowaterweek.eg/). Human interventions are creating new patterns of recharge at the surface of the system due to increasing extractions of groundwater and return flows of irrigation and drainage waters. This has resulted in additional problems affecting groundwater quality and quantity in almost all of the five locations mentioned earlier (e.g. the expansion of drainage lakes and waterlogging problems in the Siwa depression [18, 19]).

At present, these new inflows and return flows of water to the multi-layer hydrological system do not appear to reach far into the Western desert, and the waste waters from the Northern coastal areas are still mostly flushed out into the sea. There are growing concerns about the sustainability of the NSAS in areas where it is increasingly used for irrigation [20]. However, a concerted effort to explore the scope for the productive reuse of wastewaters and nutrients is taking place in Egypt. This may change the patterns of water use and waste disposal at the surface of the NSAS. Although to date, the total recharge to the system has been estimated at only 3–4% [21], this does not yet take into account the changes that are taking place at the surface. Nor does it consider the full significance of human powers for innovation that are already transforming desert landscapes across Egypt and lining the coasts with desalination systems. The balance of recharge sources to the multi-layered system in Egypt's Western Desert is therefore could change rapidly over the coming years.

Periodically, ambitious proposals for water transfers to transform the Western Desert have been made. These have included many ambitious schemes that have not been implemented, e.g. to flood the Qattara depression (see Fig. 2) with seawater, or to pump drainage water out of waterlogged areas around the lakes in the Siwa depression. But other such schemes have been realized across Egypt—leading to the creation of artificial lakes and rich new biodiverse ecosystems such as Wadi Rayan.

Another visionary plan for a "Desert Development Corridor" in Egypt, researched and created by Boston University geologist Dr. Farouk El-Baz. El-Baz's idea has two components: first, an axis composed of a north-south running eight-lane highway, a high-speed train, an electricity line, and a water pipeline from the Toshka Canal to supply freshwater for human consumption along the 1,200 km strip of desert [17].[1] In a world where such feats of innovation and environmental engineering are possible, the population is expanding, and real-estate values are continuously rising, the further spread of developments relying on engineered flows of water across the Western desert is probably inevitable.

The very important questions concern the nature of the new systems of engineered hydrological and ecological processes that will emerge, and the future balance of flows from desalination of seawater, wastewater and brackish groundwaters versus the conservation and use of the precious fresh groundwater reserves from the deeper layers of the NSAS. These are human decisions that the current generation in Egypt is making for the future generations. A large number of wells have been installed across the Western Desert, and many of them have begun pumping out non-renewable sources of water (see the Chapter authored by Abdelkhalek and King in this book). The Egyptian government expects to be able to control how rapidly these wells will be pumped and to manage the sustainability of the new system that it is creating.

Extraction rates in Libya, Western Sudan and Chad may be less predictable. However, at the local level, communities across all four countries aspire to conserve and enhance the basic functioning of the systems that will enable them and their children to subsist and prosper. This reality is a sufficient basis for cooperation and mutual benefit (Fig. 3).

Background to the Sustainable Utilization of Groundwater in Transboundary Systems

Two major international instruments are available to guide the sustainable utilization of groundwater in transboundary systems, such as the NSAS. These provide a series of norms and options but require the States within each transboundary system to negotiate and shape their own context-specific agreements, according to their own particular capabilities and needs.

First, the UN General Assembly adopted Resolution A/RES/63/124 on the law of transboundary aquifers in 2009.[2] This Resolution provided draft articles in an annex, including provisions on defining opportunities for cooperation among aquifer States including the regular exchange of data, monitoring (jointly or not), and joint management. These articles did not fully engage with the significance of human innovation in land and water management processes as a driving force in the sustainable or

[1] http://blogs.bu.edu/professorvoices/2011/03/01/development-corridor/.

[2] https://www.internationalwaterlaw.org/documents/intldocs/UNGA_Resolution_on_Law_of_Transboundary_Aquifers.pdf.

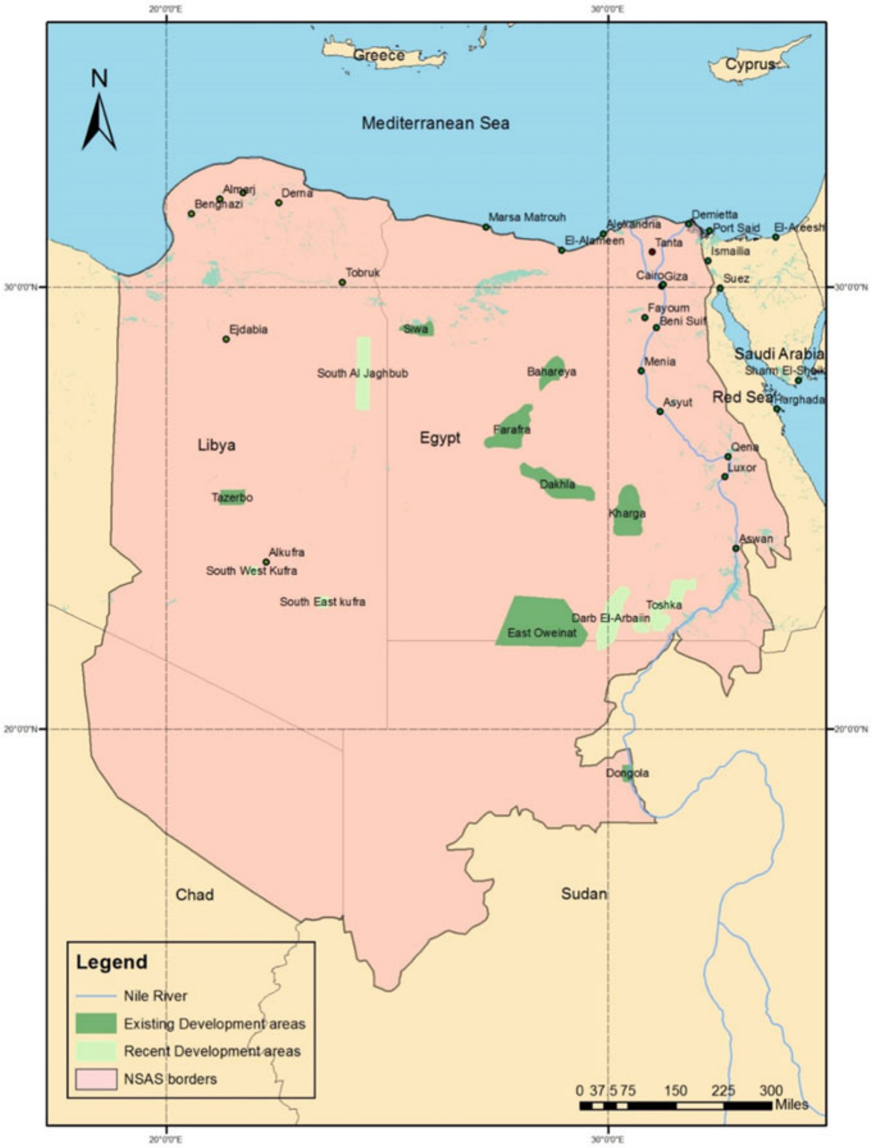

Fig. 3 Extraction zones in the Nubian Sandstone Aquifer System. *Source* Ahmed Abdelkhalek based on: [4] and https://www.nsasja.org/domain_en.php

unsustainable management of aquifer systems as is currently encountered in the NSAS. Nor do they refer in details to the full scale of the opportunity for States to peer review, backstop, encourage and independently validate one another's' efforts to understand and maximise these opportunities.

The general principles in the Draft Articles on the Law of Transboundary Aquifers adopted by the United Nations International Law Commission in 2008 (ILC Draft Articles, appended to UNGA Resolution No.63/124 of 11 December 2008) offer basic norms on equitable and reasonable use, the duty not to cause significant harm, and procedural and environmental protection norms.

Secondly, a Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) further aims to enable the sustainable use of transboundary water resources by facilitating cooperation. Initially negotiated as a regional instrument for use between States within Europe, this Convention has been amended to become universally available. As of March 2016, all Member States can accede to this Convention. Nonetheless, they must each still define their own needs and constraints and highlight the vision and capabilities that they are each bringing to the cooperative arrangement for sustainable utilization.

Overview of Transboundary Cooperation in the NSAS

The following summary of cooperation in the NSAS is partially based on previous accounts [9] as discussed previously by Quadri [22]:

An agreement for a Joint Authority for the Study and Development of the NSAS (JASD-NSAS) was first signed in 1992 (see https://www.nsasja.org/about_en.php and description at: https://programme.worldwaterweek.org/Content/ProposalResources/allfile/the_joint_authority_for_the_study_and_development_of_the_nubian_sandstone_aquifer_system.pdf). An "internal regulation" of the Authority, sets out the internal structure, functions, decision-making process, and funding of the Authority. The agreement included no provisions regarding the management of the NSAS or the groundwater stored in it. The mandate of the JASD-NSAS is to collaborate and develop co-operative activities for the sustainable mutual development of the NSAS, including monitoring the status of utilization of the aquifer and evaluation of the progress and activities enacted on the regional and national levels. As of 2019, the JASD-NSAS has held 20 meetings.

Two agreements made in 2000 through a Global Environment Facility (GEF)-funded project implemented by CEDARE provided the basis for a "Programme for the Development of a Regional Strategy for the Utilization of the NSAS". These agreements required that regular monitoring, updating and sharing of data and information from the NSAS should inform the sustainable use of the aquifer's groundwater resources. Regarding monitoring and information exchange, the four NSAS countries agreed to share data collected and analysed. For information on the Formulation of an Action Programme for the Integrated Management of the Shared Nubian Aquifer (2006–2011) see: https://iwlearn.net/iw-projects/2020/.

A further step in the process of cooperation between the NSAS countries was the “Regional Action Programme for the Integrated NSAS Management”, funded by the GEF and implemented by UNDP, IAEA, and UNESCO-IHP [21]. This project supported the development of a regional strategy for the integrated NSAS management, aimed at the equitable long-term exploitation of the aquifer. The project fostered a better understanding of aquifer issues and responses, while laying the basis for a regional Strategic Action Plan (SAP).

The SAP agreement, signed by the NSAS countries and the Joint Authority in 2013, committed Parties to agree on actions for the sustainable management of the aquifer. In 2018, support for a project on Enabling implementation of the Regional SAP for the rational and equitable management of the NSAS was approved by the GEF [9].

Challenges and Way Forward

To date, Egyptian transboundary groundwater management initiatives have been state-led, and have focused on the generation of studies with the intent to share hydrological data between countries on the hydrological conditions of the aquifer. This is intended to enhance management and coordination. However, this hydrological data sharing is slow and sometimes sensitive. Furthermore, it has been difficult for the transboundary groundwater management initiatives to get to grips in any practical way with the challenge of sustainable groundwater use. Also, the political instability which still continues to this day in Libya (following revolutions in Egypt, Sudan and Libya) is also another big challenge affecting initiatives for cooperation between the four neighbouring countries who share the NSAS water resource.

Egypt can share its expertise in well-drilling technologies, and try to encourage other states to establish more effective archives to store and analyse the hydrogeological profiles and information that is generated during the drilling process. This will help to improve groundwater management knowledge, across the shared aquifer, including in Egypt.

Ecological management practices to conserve the health of the land that stores the groundwater reserves, and enable their replenishment (Table 1) have so far received little attention in transboundary groundwater management programmes. Yet these practices can make a major difference to water resource availability and its productive uses. They can conserve the quality of groundwater reserves from contamination threats, enhance the conditions for recharge (enlarging the volume of recharge), and establish virtuous cycles of use and reuse to make more uses of less water. Effective drainage and treatment technologies, including desalination can also further add to water resource availability. All of these affect the water balance calculations and the sustainability of the groundwater resource on a local scale.

Also the use of non-conventional sources of energy such as solar and wind for the pumping of wells’ water can help in the conservation of the ecology and groundwater quality. In Egypt, there is an increasing expansion in the use of solar energy for

Table 1 National targets for land degradation neutrality (sustainable development goal 15.3) in NSAS

Egypt 2018 (2015–2030)	Sudan 2018 (2010–2030)	Chad 2015 (2040)	Libya (NA)
LDN at the sub-national scale: • LDN is achieved in the land degradation hotspots: Kafr El Sheikh Governorate, Demiata Gov., Rasheed area, El Minia Gov., Sohag Gov., Al Fayoum, Mersa Matrouh Gov. (Fuka – El Sallum), El Khattara area, El Tina Plain area, El Farafra oasis and North Sinai in Egypt by 2030 as compared to 2015 and an additional 10% of the degraded hotspot areas has improved (net gain) Specific targets to avoid, minimize and reverse land degradation: • Improve productivity and carbon stocks of 3,342 km^2 (802,080 feddan) of cultivated areas by 2030 • Restore and increase the productivity of 11,666 km^2 (2,800,000 feddan) of cropland using modern agricultural techniques and SLM practices in the northern areas, western and eastern fringes of reclaimed lands of Nile Delta and El Tina Plain area by 2030 • Rehabilitate and increase the productivity of 8,000 km^2 (1,920,000 feddan) of rangeland and rainfed areas using SLM practices in the north coastal areas (rangelands and rain-fed farming areas) by 2030 • Rehabilitate and increase the productivity of 7,500 km^2 (1,800,000 feddan) of cropland using SLM practices in the reclaimed areas in western desert fringes of middle and upper Egypt Governorates by 2030	• Reservation of 15% of the country to be registered by the government as renewable natural resource area • LDN is achieved (no net loss); Sub-national targets: • Determine the productivity of pastoral land in each state and increase it to 2.5 tons/ha; • Forest conservation and reforestation of 66 square kilometers of degraded forests • Improving the quality of pastures' soil and SOC; • Improve production in rainfed agricultural areas (clay) to mean 10 Shawwal per feddan (and sand) 5 Shawwal per feddan; • Increase the carbon stock in the soil by 30,5742 tons • Cultivation of trees and shrubs of high nutritional value in the pasture lands in the semi-desert and savannah-poor areas, especially in the area of 12,563 km^2; • Raising the productivity of declining agricultural areas (15,496 km^2) and cropland with early signs of decline (59,719 km^2) and stable but stressed (32,467 km^2) (Sudan also has set specific targets to improve land use inventory, sustainability planning, implementation and evaluation in state agencies)	• By 2040, 1 738.8 km^2 of forest will be restored • By 2040, 17.95 km^2 of wetlands will be restored By 2040, 29 000 km^2 of degraded land (bare soils and other) will be restored	na

(continued)

Table 1 (continued)

Egypt 2018 (2015–2030)	Sudan 2018 (2010–2030)	Chad 2015 (2040)	Libya (NA)
• Reclamation and cultivation of 6,300 km^2 (1.5 million feddan) of virgin land in reclaimed desert soils at different locations in the western desert of Egypt by 2030 • Gain in land productivity and SOC stocks in about 8,333 km^2 of cropland in reclaimed desert lands at different location (cultivated areas) by 2030 as compared to 2015 • Halt the conversion of cropland to other land cover classes by 2030 • Increase by 25% forest cover/tree cover through agroforestry and SLM in existing forests by 2030 as compared to 2015 • Halt the occurrence of soil erosion by rain water, creating dams for water harvesting to be utilized for agricultural purposes for an area of 2,500 km^2 in dry valleys of elevated areas of the inland Sinai and Eastern Desert by 2030 Rationalize water consumption by growing crops of low water requirements and adopting modern irrigation systems for around 1,000 km^2 in some oases in the western desert of Egypt by 2030			

(continued)

Table 1 (continued)

Egypt 2018 (2015–2030)	Sudan 2018 (2010–2030)	Chad 2015 (2040)	Libya (NA)
Link: https://knowledge.unccd.int/home/country-information/countries-having-set-voluntary-ldn-targets/egypt	https://knowledge.unccd.int/home/country-information/countries-having-set-voluntary-ldn-targets/sudan	https://knowledge.unccd.int/home/country-information/countries-having-set-voluntary-ldn-targets/chad	na
Date of Voluntary National Review of Progress report on SDG: 2018 Link: https://sustainabledevelopment.un.org/content/documents/20269EGY_VNR_2018_final_with_Hyperlink_9720185b45d.pdf	2018 https://sustainabledevelopment.un.org/content/documents/21741VNR_Sudan.pdf	2020 https://sustainabledevelopment.un.org/content/documents/23405RAPPORT_NATIONAL_VOLONTAIRE_FINAL_TCHAD.pdf	2019 https://sustainabledevelopment.un.org/content/documents/26753Libya_VNRLIBYA2020part1.pdf

running wells in the Western desert and some other areas in the recent years. The number of wells running with solar energy is still not too big compared to the total number of wells all over Egypt but it's increasing. Moreover, the applications of decentralized solar water pumping solutions in the agro-food sector have a strong potential for creating jobs in both small and medium enterprises [23].

Egypt has a major wealth of emerging experience to share concerning land and water management practices that can be integrated with and contribute to the sustainable utilization of groundwater, as described earlier in this chapter (see CWWW proceedings: http://www.cairowaterweek.eg/).

Notable technological innovations include growing insights from the management of the new systems of engineered hydrological and ecological processes [e.g. 24, 25]. Practices to conserve the health of the land that stores the groundwater reserves, including reductions in the use of agrochemicals and the safe disposal of wastes at the surface are particularly important [26–30]. The study of runoff and recharge process that enable the local replenishment of aquifers is also critical. There are also new management options appearing for the future balance of flows from desalination of seawater, wastewater and brackish groundwaters versus the conservation and use of the precious fresh groundwater reserves from the deeper layers of the NSAS.

Groundwater users in Egypt can draw on a range of technologies that could help to support and sustain productive activities in groundwater dependent environments. These include technologies to deliver, regulate and monitor the flows of water for different uses, including uses of saline water either with or without desalination. All of these can be of direct practical use and interest to groundwater dependent communities in the other three riparian countries.

To monitor and sustain the hydrological, ecological and socio-economic aspects of groundwater management requires the engagement of local institutions to conduct or facilitate the monitoring and to implement the management practices [31]. For them, it is important not only to pursue the sustainable management of the transboundary system over the longer term, but also to consider how the monitoring systems and information can be used to improve the viability of local resource management in the short term.

Several promising areas for potential cooperation and knowledge exchange can be identified. States could exchange points of view to articulate specific good practices and intentions in relation to the following:

(1) There is an opportunity for new monitoring systems to be incorporated into new groundwater developments, such as those in the Western Desert of Egypt. These should support sustainable integration of ecological and hydrological management, as well as enabling and contributing to monitoring of broader changes in the hydrological systems.
(2) Increasing understanding of the functions and value of the desert ecosystems is inspiring new approaches to their conservation and use.

(3) Innovative approaches to the management of wastewater, drainage and nutrients and plant assemblages at the surface of the systems can reshape the availability and demands for water to be extracted from the deeper layers and affect localized recharge processes
(4) In some cases, innovations in the use of solar-powered energy systems are decreasing the operating costs of groundwater management technologies.
(5) Database creation and management at the local and national levels remains a significant challenge area that is holding back effective knowledge accumulation, analysis and exchange across the transboundary systems. There is scope for identification of good practices and lessons learned e.g. in the compilation and analysis of hydrogeological profiles gained from drilling activities.
(6) The over-arching challenge of institution-building for groundwater management requires continuous attention. This includes the need to build, resource and sustain functioning institutions at the local level.

Conclusions

This chapter has highlighted some of Egypt's experiences in monitoring and managing the groundwater in the NSAS. The NSAS is the heavyweight of aquifer systems in Africa and worldwide. Egypt is already a world leader in transboundary groundwater management and regional cooperation on water management issues more broadly. Egypt has growing capability and options to reshape and manage the balance between extraction and recharge of the NSAS over the coming years. There is no physical or technological barrier nor any other reason why Egypt and its neighbours should not achieve the sustainable utilization of their aquifer system. However, this will require a major concerted scientific and institutional effort. To achieve this, Egypt and its partners must look well beyond the current international norms and conventions for transboundary groundwater management cooperation, and lead the way forward to a more sustainable future.

Recommendations

- The main recommendation is to build local capacities to manage land quality and recharge patterns in the surface layers, as well as to conserve and protect the reserves stored in the deeper layers.
- Egypt and its partners must look well beyond the current international norms and conventions for transboundary groundwater management cooperation since these do not give sufficient consideration to best practices in land and water management
- States could more fully engage with the significance of human innovation in land and water management processes as a driving force in the sustainable or

unsustainable management of aquifer systems as is currently encountered in the NSAS.

- Egypt should develop and evaluate possible strategies to reshape and manage the balance between extraction and recharge of the NSAS and its associated multi-layered aquifer systems over the coming years, taking into consideration local ecological effects and return to the aquifer, as well as flows of water through the aquifer.
- States should peer review, backstop, encourage and independently validate one another's' efforts to understand and maximise the sustainable management of the aquifer system.
- Egypt should demonstrate leadership by leading the way forward to achieve the sustainable utilization and management of the shared aquifer system, taking into consideration ecological management processes and options as well as quantifying hydrological flows and deepening understanding of hydrogeological conditions.
- This will require the strengthening of management institutions at both local and national levels

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