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Overview of groundwater in the Nile River Basin

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Key messages

- Groundwater is gaining increasing recognition as a vital and essential source of safe drinking water throughout the Nile Basin, and the demands in all human-related sectors are growing. The technical and regulatory frameworks to enable sustainable allocation and use of the resource, accounting for environmental service requirements, are largely not in place.
- The hydrogeological systems, and the communities they support, are highly heterogeneous across the basin, ranging from shallow local aquifers (which are actively replenished by rainfall recharge, meeting village-level domestic and agricultural needs) through to deep regional systems (which contain non-replenishable reserves being exploited on a large scale). A uniform approach to management under such circumstances is inappropriate.
- The database and monitoring systems to support groundwater management are weak or non-existent. With few exceptions, groundwater represents an unrecognized, shared resource among the Nile countries.
- Most Nile countries have strategic plans to regulate and manage groundwater resources but, so far, these largely remain on paper, and have not been implemented.

Introduction

Groundwater has always been essential for human survival throughout Africa, and this is the case in the Nile River Basin (NRB; UNEP, 2010). Traditionally, groundwater was accessed first at naturally occurring springs and seepage areas by humans and animals; later, as human ingenuity increased, it was accessed via hand-dug wells, advancing to hand-pumps and then to boreholes and mechanized pumps. Throughout the NRB we can see all of these forms of groundwater access in use today. As the population's ability to develop and use technologies to access groundwater has grown, the scale of abstraction and human demand on groundwater resources have also increased. Masiyandima and Giordano (2007) provide a good overview of the exploitation of groundwater in Africa. Groundwater use the NRB includes domestic water supply in rural and urban settings for drinking and household use and small commercial activities; industrial use and development for tourism; agricultural use for irrigation and livestock

production, from subsistence through to commercial scales; and large-scale industrial activities, such as mineral exploitation.

The overall type and distribution of the primary aquifers in the region have been quite well known since the mid-twentieth century (Foster, 1984). However, quantitative information on characteristics such as recharge rates, well yields and chemical quality is less consistent and depends largely on specific surveys largely generated by prospecting within a particular area. The same can be said for knowledge on the groundwater resource at the national level: groundwater is extensively utilized within the Egyptian part of the NRB, and therefore there is an abundance of data at the local and national level (although this may not be compiled to best manage the resource as a whole). This can be compared with upstream Uganda, where until recently most groundwater use was traditional hand-dug shallow wells for domestic use and supplementary irrigation, and there is limited quantitative data to enable management of the resource. However, groundwater in Uganda, and Africa as a whole, is essential for domestic water supply.

This chapter provides an overview of the groundwater within the NRB, and the uses, monitoring, policy and regulations relating to groundwater in four of the Nile countries (Egypt, Ethiopia, Sudan and Uganda), based on the current situation and available literature. The sections on regional hydrogeology, groundwater recharge rates, distribution and processes provide a summary of the known physical characteristics of the NRB aquifers. We discuss current and potential utilization of groundwater in the NRB in the section on groundwater utilization and development; the section on monitoring and assessment of groundwater resources briefly examines the current state of groundwater monitoring, while the section on policy, regulation and institutional arrangements for groundwater resource management provides an overview of some of the policy and regulatory arrangements and constraints. As statistics on utilization and development plans are normally based on national boundaries, and given the wide range in the type and form of data available, we address current groundwater use, potential, monitoring and regulation on a country basis. The final section offers some concluding remarks on groundwater in the basin.

Regional hydrogeology

The regional hydrogeological framework for the NRB and surrounding regions is well-defined as a result of several decades of effort resulting in the development of hydrogeological maps at the continent scale. Within the NRB (and the continent as a whole), there are four generalized types of hydrogeological environments: crystalline/metamorphic basement rocks, volcanic rocks, unconsolidated sediments and consolidated sedimentary rocks (Figure 10.1; Table 10.1; Foster, 1984; MacDonald and Calow, 2008).

Basement rocks comprise crystalline igneous and metamorphic rocks of the Precambrian age and are present across the area, but mainly in the upstream parts of the basin. With the exception of metamorphic rocks the parent material is essentially impermeable, and productive aquifers occur where weathered overburden and extensive fracturing are present. Consolidated sedimentary rocks are highly variable and can comprise low permeability mudstone and shale, as well as more permeable sandstones, limestones and dolomites. They tend to be present in the lower parts of the basin, forming some of the most extensive and productive aquifers. In the more arid regions, large sandstone aquifers have extensive storage, but much of the groundwater can be non-renewable, having originated in wetter, past climates. Unconsolidated sedimentary aquifers are present in many river valleys. Volcanic rocks occupy the NRB uplands (mainly the Ethiopian Highlands), where they form highly variable, and usually highly important, productive aquifers.

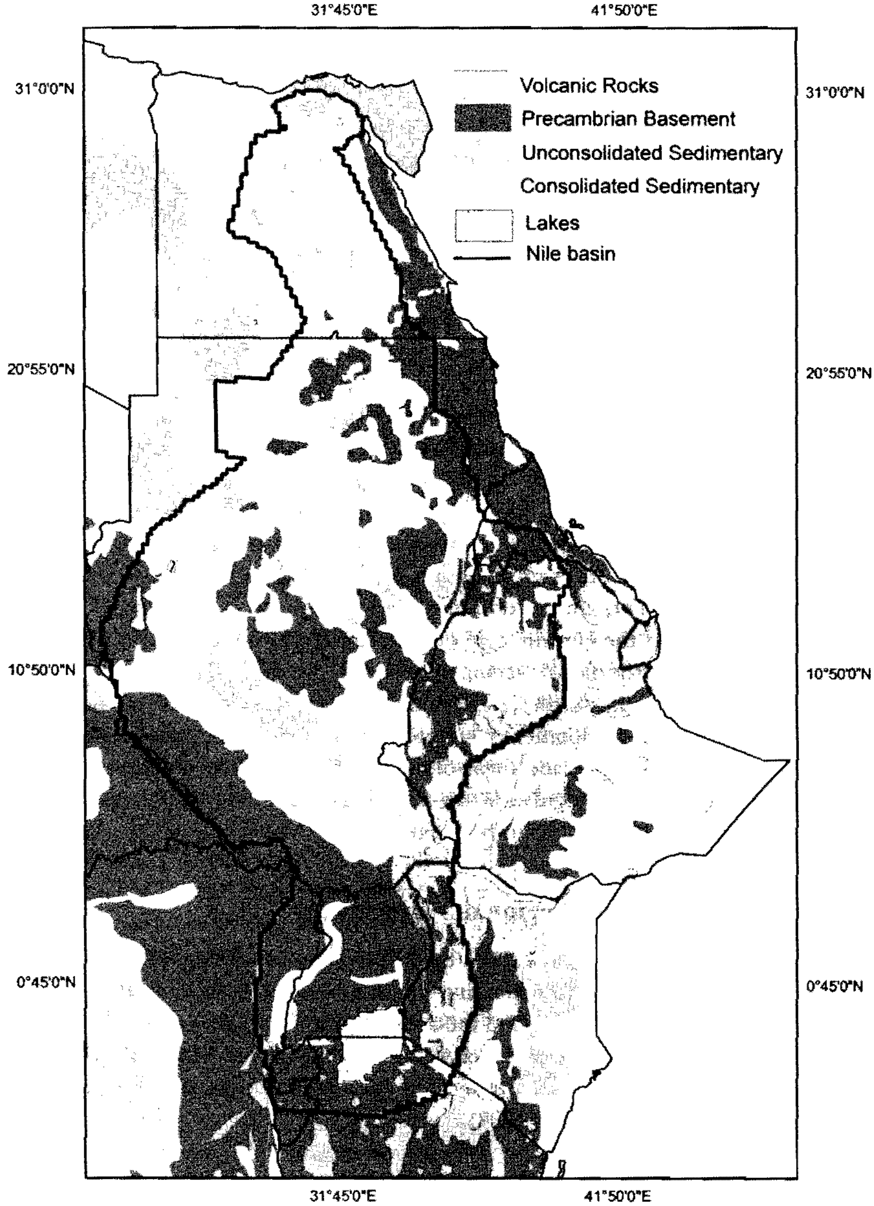

Figure 10.1 Generalized hydrogeological domains of the Nile River Basin

Source: Adapted from MacDonald and Calow, 2008

The upstream NRB reaches of Uganda are characteristic of a crystalline bedrock setting. Here aquifers occur in the regolith (weathered rock) and in the fractured rock (unweathered), typically at greater depth. If the regolith thickness is large, weathered rock aquifers may have a good well yield; however, generally, the more productive aquifers are found in the contact zone

Table 10.1 General characteristics of the aquifers within the Nile River Basin

Country	*Basin/region name*	*Hydrogeological environment*	*Depth (m)*	*Depth to SWL (m)*	*Yield* ($l\ s^{-1}$)	T^2 ($m^2\ d^{-1}$)	S^3
UGA	Country-wide	Basement rock + alluvial			0.2–13.9	16–34	0.011–0.21
ETH	Abay Basin	Volcanic and basement	60–252	AR^4–138	0–2.5	31–2157	
ETH	Abay and Baro-Akobo basins (northwest and west)	Dominantly volcanic	56–100	0.8–73	0.8–30	1–2630	
ETH	Tekeze (north and northwest)	Volcanic, sedimentary and basement		51–180	32–168	0.0–2.5	32–240
SUD	El Gash	Unconsolidated (alluvial)			0.6–1.2	1000	10^{-1}–10^{-2}
SUD	Bara	Detrital Quaternary & Tertiary deposits			0.1–5.8	35–210	10^{-2}
SUD	Baggara	Detrital Quaternary & Tertiary deposits			0.2	130–880	10^{-3}–10^{-5}
SUD	Seleim	Consolidated (NSAS)			2.3–5.8	1500	10^{-2}
SUD	Khartoum	Consolidated (NSAS)			0.5–1.6	250	10^{-3}–10^{-4}
EGY	Nile Delta	Unconsolidated		0–5		500–1400	
EGY	Nile Valley	Unconsolidated		0–5		<50,000	
EGY	Kharga	Consolidated (NSAS)		0–30		1000–2800	
EGY	Natron/Qattara	Consolidated (Mohgra)		100			
EGY	Wadi Araba	Consolidated (Carbonate)		AR^4			

Notes: SWL = standing water level; UGA = Uganda; ETH = Ethiopia; SUD = Sudan (North and South); EGY = Egypt; T^2 = transmissivity; S^3 = storativity; AR^4 = artesian conditions; NSAS = Nubian Sandstone Aquifer System.

Sources: Authors' data; Tindimugaya, 2010; El Tahlawi and Farrag, 2008

between the regolith and bedrock due to higher aquifer transmissivity associated with the courser grain sizes and less secondary clay minerals. The highest yielding aquifers are the fractured bedrock if the degree of fracturing is high and hydraulically connected to the overlying regolith which, although low in permeability, provides some degree of storage and replenishment. The weathered aquifer is unconfined whereas the fractured-bedrock aquifer is leaky and the two aquifers form a two-layered aquifer system (Tindimugaya, 2008). Alluvial and fluvial aquifers are found adjacent to major surface water courses. The aquifers are found at relatively shallow depths, with average depths for shallow wells of 15 m and boreholes of 60 m.

The hydrogeological setting in the Ethiopian part of the basin is extremely complex, with rock types ranging in age from Precambrian to Quaternary, with volcanic rocks most common in the highlands and the basement, and complex metamorphic and intrusive rocks in peripheral lowlands and a few highland areas (Chernet, 1993; Ayenew *et al.*, 2008). Sedimentary rocks cover incised river valleys and most recent sediments cover much of the lowlands of all the major river sub-basins. The areas of Precambrian basement terrain are particularly complex due to various tectonic events. Groundwater flow systems, known from studies conducted in sub-basins such as Tekeze and Abay, suggest an intricate interaction of recharge and discharge, operating at local, intermediate and regional scales (Kebede *et al.*, 2005). Springs are abundant at different topographic elevations, suggesting that the shallow groundwater operates under local flow systems controlled by static ground elevation. However, the thickness and lateral extent of the aquifers indicate that deeper, regional flow systems operate mainly in the volcanic and sedimentary rocks. Most of the Precambrian rocks have shallow aquifers. In these aquifers depth to groundwater level is not more than a few tens of meters. From a database of 1250 wells from across the country, Ayenew *et al.* (2008) showed that the yields of most shallow and intermediate aquifers do not exceed 5 l s^{-1}, whereas the highly permeable volcanoclastic deposits and fractured basalts of Addis Ababa and Debre Berehan areas, for example, can yield between 20 and 40 l s^{-1}, respectively. Recent drilling in deep volcanic aquifers has located highly productive aquifers, yielding over 100 l s^{-1}. Depth to the static water level in the unconfined aquifers in alluvial plains and narrow zones close to river beds do not normally exceed 10 m except in highland plains, where it is around 30 m. Seasonal water table fluctuations rarely exceed 2 m.

Groundwater in the Sudanese part of the NRB lies within a multi-structural system of rifts, which range in age from the Paleozoic through to the most recent Quaternary and have resulted from the accumulation and filling with consolidated and unconsolidated sediments. Rift structures in Sudan also act as reservoirs for hydrocarbon reserves at greater depths. The major hydrogeological formations in Sudan include the Nubian Sandstone Aquifer System (NSAS), the Umm Ruwaba, Gezira sedimentary aquifer, the unconsolidated alluvium *khors* (seasonal streams) and *wadis*, and the Basement Complex aquifers. The NSAS may attain a thickness of 500 m, and is found under water table (unconfined) conditions or semi-confined artesian conditions. In some areas (e.g. northern Darfur), the NSAS is overlain by volcanic rocks. The Umm Ruwaba sediments are characterized by thick deposits of clay and clayey sands under semi-confined to confined conditions. The Basement Complex, extending over half of Sudan, is a very important source of groundwater. Unless subjected to extensive weathering, jointing and fracturing the parent rock is largely impervious. In the White and Blue Nile sub-basin sands and gravels in the Gezira and El Atshan Formations constitute important aquifers. Quaternary and recent unconfined aquifers tend to comprise a few metres of sand, silt and clay as well as gravel.

In Egypt, the major aquifers are generally formed of either unconsolidated or consolidated granular (sand and gravel) material or in fissured and karstified limestone. The hydrogeological provinces present within the NRB include the Nile Valley and Delta aquifers, Nubian sandstone aquifer, Moghra aquifer, tertiary aquifer, carbonate rock aquifers and fissured basement aquifers. The hydrogeological characteristics and extent of each hydrogeological unit are generally well known. The Nile Valley aquifer, confined to the floodplain of the Nile River system, consists of fluvial and reworked sand, silt and clay under unconfined or semi-confined conditions (Omer and Issawi, 1998). The saturated thickness varies from a few metres through to 300 m. This high storage capacity, combined with high transmissivity (5000–20,000 m^2 day^{-1}) and active replenishment from the river and irrigation canals makes the aquifer a highly valued

resource. The Nile Delta consists of various regional and sub-regional aquifers with thicknesses of up to 1000 m. Much like the Nile Valley aquifer, the delta aquifers are composed of sand and gravel with intercalated clay lenses and are highly productive with transmissivities of 25,000 m^2 day^{-1} or more (El Tahlawi and Farrag, 2008). The NSAS is an immense reservoir of non-renewable (fossil) fresh groundwater that ranks among the largest on a global scale, and consists of continental sandstones and interactions of shales and clays of shallow marine of deltaic origin (Manfred and Paul, 1989). The 200–600 m thick sandstone sequence is highly porous with an average bulk porosity of 20 per cent, in addition to fracture-induced secondary porosity. Aquifer transmissivities vary from 1000 to 4000 m^2 day^{-1}. The Moghra aquifer is composed of sand and sandy shale (500–900 m thick) and covers a wide tract of the Western Desert between the Delta and Qattara Depression. The water in this aquifer is a mixture of fossil and renewable recharge. Discharge takes place through evaporation in the Qattara and Wadi El Natron depressions and through the lateral seepage into carbonate rocks in the western part of the Qattara Depression. The fissured and karsified carbonate aquifers generally include three horizons (lower, middle and upper) separated by impervious shales. Recharge to the aquifer is provided by upward leakage from the underlying NSAS and some rainfall input. The flow systems in the fissured limestone are not well understood, but it is known that surface outcrops create numerous natural springs. Hard rock (metavolcanic) outcrops are found in the Eastern Desert and beyond the NRB in South Sinai.

Groundwater quality and suitability for use

Data on groundwater quality in the NRB vary widely from country to country, but are generally restricted to the major constituents with a few exceptions. Time series are largely absent, except in Egypt where a groundwater quality monitoring network is well established (Dawoud, 2004), and more generally when associated with monitoring of public water supply wells (Jousma and Roelofsen, 2004). Spatial coverage is limited. Based on the available data, groundwater quality is known to be highly variable and influenced by the hydrogeological environment (granular, hard rock), type of water sources (tube wells, dug wells, springs) and level of anthropogenic influence.

In the Ugandan part of the basin, groundwater quality in most areas meets the guideline requirements for drinking water with the exception of iron and manganese in highly corrosive low pH groundwater, and nitrates in densely populated areas associated with poor sanitation (BGS, 2001). In hydrochemical terms, the groundwater is fresh, and contains a mixture of calcium–magnesium sulphate and calcium–magnesium bicarbonate types of water, which result from differences in the water–rock interactions. Generally, calcium bicarbonate groundwaters are younger and found under phreatic conditions, whereas calcium sulphate waters are older (Tweed *et al.*, 2005).

Generally groundwater quality is naturally good throughout the Blue Nile Basin (BNB), with freshwater suitable for multiple uses (Table 10.2). There are some localized exceptions, including salinity due to mineralization arising from more reactive rock types or from pollution due to urbanization, particularly underlying areas of highly permeable unconsolidated sediments in waters drawn from hand-dug wells and unprotected springs (Demlie and Wohnlich, 2006). The groundwater is dominantly fresh with total dissolved solid levels less than 200 mg l^{-1}, with pockets of elevated salinity evident in deep boreholes due to the presence of gypsum in sedimentary rocks of the Tekeze sub-basin and in the Tana sub-basin (Asfaw, 2003; Ayenew, 2005). Hydrochemical facies include bicarbonate, sulphate and chloride types, with calcium and magnesium being the dominant cations bringing associated hardness to the water.

The amount of the solute content depends on the residence time of groundwater and the mineral composition of the aquifer resulting in, for example, elevated mineral/salinity content in deep sedimentary aquifers due to extended residence times. Naturally high levels of hydrogen sulphide and ammonia can be present in deep anaerobic environments or shallow organic carbon-rich (swampy) areas and cause problems of taste and odour.

Fluoride is a major water-related health concern and is present at levels above drinking water standards in a number of localities, particularly in the western highlands, including waters emanating from hot springs (Kloos and Tekle-Haimanot, 1999; Ayenew, 2008) and within the Ethiopian rift volcanic terrain, adjacent to the NRB. Ethiopia recognizes the issue of high localized levels of fluoride in groundwater (e.g. Jimma) and is hosting the National Fluorosis Mitigation Project (NFMP). According to the Ministry of Health and United Nations Children's Fund (UNICEF), 62 per cent of the country's population are iodine-deficient. Nitrate contamination of groundwater, derived mainly from anthropogenic sources including sewerage systems and agriculture (animal breeding and fertilizers), is already a problem in rural and urban centres. This is worst in urban areas close to shallow aquifers. High nitrate concentrations thought to originate from septic tank effluents have been detected in several urban areas including Bahirdar, Dessie and Mekele (Ayenew, 2005). Several small towns and villages utilizing shallow groundwater via hand-dug wells have reported problems of nitrate pollution from septic pits (Alemayehu *et al.*, 2005).

The most common source of poor water quality in groundwater (and surface water) in Ethiopia is microbiological contamination, primarily by coliform bacteria. Poor management of latrine pits and septic systems in both rural and urban areas continues to lead to faecal contamination of groundwater, for example, digging septic pits too close to drinking water wells. Many urban populations still rely on hand-dug wells and unprotected springs as a drinking water source and these are frequently contaminated. The Ministry of Water Resources is developing national water quality guidelines. However, enforcement of any guidelines will need to be backed up by extensive training and education campaigns at all levels in rural and urban areas.

Within North and South Sudan, Nubian aquifers are considered to contain the best quality groundwater and are generally suitable for all purposes. The salinity of the groundwater varies from 80 to 1800 mg l^{-1}. More saline water is associated with down-gradient areas having enhanced residence times; shallow water table areas due to enrichment from evaporation and evapotranspiration, mineralization from claystones, mudstones, basalts, dissolution from salt-bearing formations and mixing with overlying Tertiary and Quaternary aquifers. Nubian groundwater is mainly sodium bicarbonate type, with calcium or magnesium bicarbonate waters common near the recharge zones. The salinity of the Umm Ruwaba sedimentary formation, the second most important groundwater source after the NSAS, is generally good but may rise to over 5000 mg l^{-1} along the margins. Groundwater quality is a major determinant in location and type of groundwater development that can take place. In one of the few reported studies on groundwater quality in Sudan, groundwater production wells in Khartoum State, east of the Nile and the Blue Nile rivers, reveal the NSAS groundwater is largely fit for human and irrigation purposes except at a few localities, due to elevated major ion levels (Ahmed *et al.*, 2000). Groundwater quality tends to be measured only in association with development activities to test suitability and ensure human health.

Within the Nile Valley region in Egypt, groundwater is of good quality (<1500 mg l^{-1} total dissolved solids, TDS, and mainly used for irrigation and domestic purposes; El Tahlawi and Farrag, 2008). In the valley margins remote from surface water systems to the east and west, the groundwater salinity tends to be more elevated (Hefny *et al.*, 1992). The groundwater in the

Nile Delta, which is primarily fed by the Nile River, is of higher quality in the southern part (<1000 mgl^{-1}), as compared with the north close to the Mediterranean Sea coast where there is a marked increase in salinity due to seawater intrusion. Water quality variations are complex and affected by various physical and geochemical processes. Wadi El-Natrun, situated within the Western Desert adjacent to the delta has moderate salinity (1000–2000 mg l^{-1} TDS) in the south, rising and deteriorating to the southwest (2000–5000 mg l^{-1}); whereas the Nubian waters of the Dakhla Oasis are fresh (Table 10.2). Domestic water is obtained from deep wells (800–1200 m) and is generally of very good quality except for naturally elevated levels of iron and manganese. Contamination of groundwater with nitrates in the Valley and Delta by industrial wastes around Cairo and other industrial cities and from sewer drain seepage poses a threat to public health, especially in areas where shallow hand pumps are used.

Table 10.2 Groundwater quality at three locations in the Nile Basin

Parameter[1]	*Blue Nile (Abay) sub-basin, Ethiopia*[2]	*Blue Nile sub-basin, Sudan*[3]	*Western Desert, Egypt*[4]
pH	6.99	8.0	6.39
TDS	366	340	351
Sodium	10	46	–
Calcium	49	27	25
Magnesium	10	20	13
Potassium	5	6	–
Bicarbonate	160	200	58
Chloride	20.5	24	90.8
Carbonate	9.5	–	–
Sulphate	9	18	53
Fluoride	47	0.5	–
Nitrate	47	–	1.0
Silica	40	–	7.5
Phosphate	–	–	0.04

Notes: [1] Units are mg.l^{-1}, except for pH
[2] median value quoted, *n* = 13
[3] Al-Atshan aquifer from Hussein, 2004
[4] NSAS, Dakhla Oasis, *n* = 10 from Soltan, 1999

Groundwater recharge rates, distribution and processes

Sustainable development of groundwater resources is strongly dependent on a quantitative knowledge of the rates at which groundwater systems are being replenished. A reasonably clear picture of the distribution of recharge rates across the NRB has recently begun to emerge. Using satellite data from the Gravity Recovery and Climate Experiment (GRACE), supported by recharge estimates derived from a distributed recharge model, Bonsor *et al.* (2010) found values ranging from less than 50 mm yr^{-1} in the semi-arid lower (as well as upper) catchments, and a mean of 250 mm yr^{-1} in the subtropical upper catchments (Figure 10.2). Along the thin riparian valley strips recharge from surface water and irrigation seepage may be up to 400 mm yr^{-1}. The total annual recharge within the basin has been estimated at about 130 mm, or 400

km^3 in volumetric terms. High temporal and spatial rainfall variability within the basin, when combined with the contrasting surface geology, accounts for this large range and generally low rates of groundwater replenishment. Values derived from the handful of local field studies, used as independent checks, are within this range (0–200 mm yr^{-1}). At the African scale, based on a 50×50 km grid resolution, Döll and Fiedler (2008) determined recharge to range from 0 to 200 mm yr^{-1} across the NRB with similar magnitudes and patterns to those later reported by Bonsor *et al.* (2010).

There have been a number of regional and local-scale recharge studies employing a variety of methods to arrive at groundwater recharge fluxes. An annual groundwater recharge in the order of 200 mm yr^{-1}, for the 840 km^2 Aroca catchment of the Victoria Nile, central Uganda, was determined by Taylor and Howard (1996) using a soil moisture balance model and isotope data. In several of the upper subcatchments of the Blue Nile, Ethiopia, recharge was estimated at less than 50 mm yr^{-1} in arid plains and up to 400 mm yr^{-1} in the highland areas of north-western Ethiopia, using a conventional water balance approach and river discharge analysis, chloride mass balance, soil–water balance methods and river or channel flow losses (Ayenew *et al.*, 2007). Bonsor *et al.* (2010) report groundwater recharge in the Singida region of northern Tanzania to be 10–50 mm yr^{-1}. Lake Victoria river-basin average estimate of just 6 mm yr^{-1} is reported by Kashaigili (2010). Within southern Sudan, Abdalla (2010) determined recharge from direct infiltration of rainfall through the soil to be less than 10 mm yr^{-1} at distances 20–30 km away from the Nile River. Farah *et al.* (1999) examined the stable isotope composition of the groundwater at the confluence of the Blue and White Nile sub-basins and determined the contribution of modern rainfall to groundwater recharge to be minimal, with much of the recharge derived from the cooler Holocene period. In the eastern desert region of Egypt, Gheith and Sultan (2002) deduced that around 21–31 per cent of the rainfall in high rainfall years (average recurrence interval of 3–4 years) is concentrated in wadis that replenish the alluvial aquifers.

Rainfall intensity, more than amount, is often a key determinant of groundwater recharge. In the upper catchments of central Uganda, Taylor and Howard (1996) showed that recharge of groundwater is largely determined by heavy rainfall events, with recharge effectively controlled more by the number of heavy rainfall events (>10 mm day^{-1}) during the monsoon, than the total volume of rainfall. This was further supported by the more recent work of Owor *et al.* (2009).

Aquifers in the proximity of the Nile River and its tributaries receive preferentially high recharge from the base of those watercourses, and from seepage return flows in areas under irrigation. Bonsor *et al.*, (2010) estimate the values to be in the order of around 400 mm yr^{-1} (Figure 10.2).

In the Ethiopian Highland subcatchments, studies consistently revealed that groundwater recharge varies considerably in space and time in relation to differences in the distribution and amount of rainfall, the permeability of rocks, geomorphology and the availability of surface water bodies close to major unconfined and semi-confined aquifers that feed the groundwater. Across the landscape, large differences are observed in recharge between the lowlands, escarpments and highlands (Chernet, 1993; Ayenew, 1998; Kebede *et al.*, 2005).

Within the Nile Valley areas of Egypt, the Quaternary aquifer is recharged mainly from the dominant surface water, especially from the irrigation canals that play an essential role in the configuration of the water table. The aquifer is recharged by infiltration from the irrigation distribution system and excess applications of irrigation water, with some of this returned to the Nile River.

Palaeo-groundwater is a vast resource in the more arid lower reaches of the basin. The NSAS

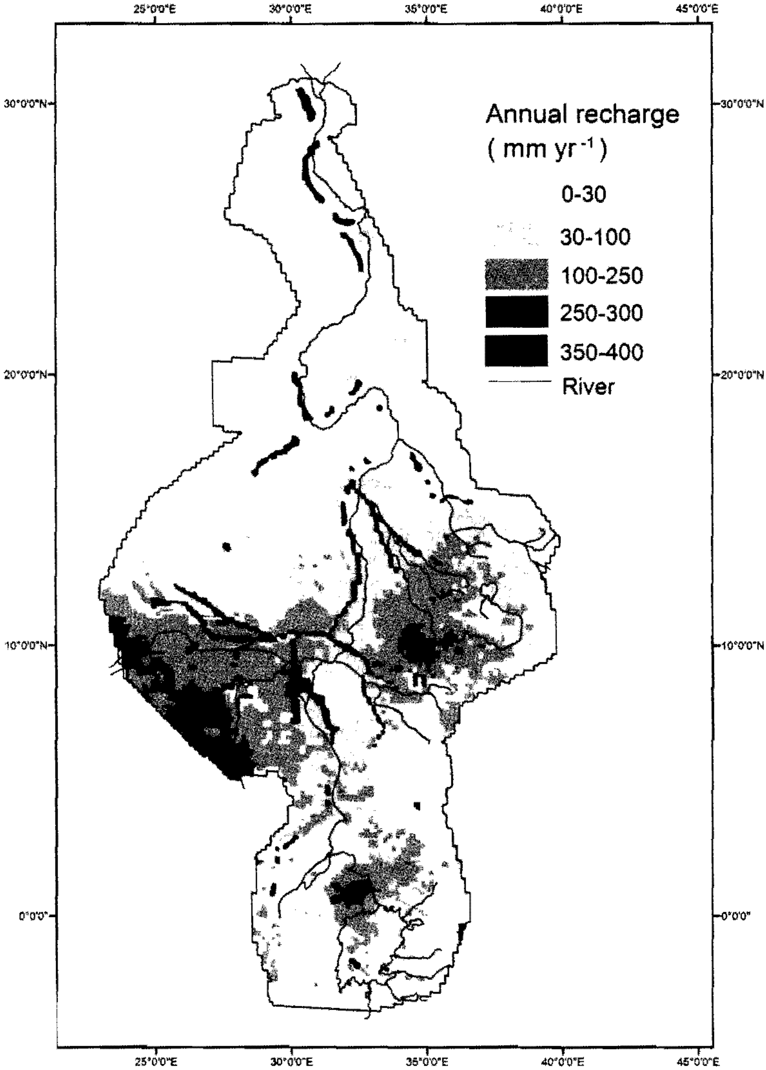

Figure 10.2 Average annual groundwater recharge map of the Nile Basin

Source: Adapted from Bonsor *et al.*, 2010

is considered an important groundwater source, but this is fossil groundwater and non-renewable due to both limited modern-day recharge and the long travel time. It has been suggested that in Pleistocene times, when more humid climatic conditions prevailed, that the NSAS was recharged by meteoric waters (Isaar *et al.*, 1972). The NSAS is found at depths and so is expensive to develop and the pumping and delivery infrastructures are also expensive to maintain. Under circumstances where the groundwater resource is poorly replenished or non-renewable, as is common across more arid environments, concepts of sustainable development must be revisited, with the intensive use of groundwater a contentious issue (Abderrahman, 2003).

Groundwater utilization and development

Throughout the NRB as a whole, the level of use or exploitation of groundwater varies widely. Groundwater is essential for drinking and for domestic water supply in most of the basin, while the use of groundwater to irrigate agricultural areas is primarily driven by the amount of rainfall and by the ease of access to, and supply of, surface waters. In the Upper Blue Nile catchment of Ethiopia, where rainfall is generally high (although seasonal droughts occur), groundwater extraction for agriculture is low compared with some areas of Egypt and Sudan where the resource is extensively developed. In some cases, the abstraction rate exceeds recharge (e.g. Gash, Sudan; see Table 10.1). Knowledge and data on groundwater use vary widely within the Nile countries (see 'Monitoring and assessment of groundwater resources' later in this chapter), although more readily available information naturally exists in those countries which rely heavily on groundwater, such as Egypt and Sudan. In the following sections we focus on four Nile countries: Uganda, Ethiopia, Sudan and Egypt.

Uganda

Historically, small-scale groundwater abstraction is widespread in Uganda, and more intensive development has been ongoing since the early twentieth century. However, abstraction remains relatively small scale when compared with potential supply, with groundwater utilized largely to satisfy rural and urban domestic demand. This is because most of Uganda has a ready supply of rainfall and surface water including large water bodies and widespread wetland areas, many of which are groundwater-fed.

Throughout Uganda, aquifers are found at relatively shallow depths (average 15 m) and the 'deep' boreholes are small-diameter wells deeper than 30 m (average 60 m). Shallow wells (less than 30 m, with an average depth of 15 m) are constructed in the unconsolidated formation. Boreholes and shallow wells are normally installed with hand pumps with a capacity of 1 m^3 hr^{-1} and their yields commonly range between 0.5 and 5 m^3 hr^{-1}. Since the early 1990s, there has been an increase in intensive groundwater abstraction for urban water supplies, utilizing high-quality groundwater with little or no treatment costs when compared with surface water. Boreholes with yields greater than 3 m^3 hr^{-1} are normally considered as suitable for piped water supply and installed with motorized pumps. In recent drilling of high-yielding boreholes in former river channels, yields of more than 20 m^3 hr^{-1} have been achieved. There are an estimated 20,000 deep boreholes, 3000 shallow wells and 12,000 protected springs in the country, utilized mainly for rural domestic water supply. Approximately 40,000 additional boreholes and 20,000 shallow wells are needed to provide 100 per cent rural water supply coverage (Tindimugaya, 2010).

While agriculture dominates the Ugandan economy, this is mostly smallholder rain-fed subsistence farming and irrigation is not widespread largely due to high investment costs, unsure returns, and lack of capacity. Most irrigation utilizes surface water with some limited upland horticulture crop irrigation using small-scale pumping systems. Traditionally, mineral-rich groundwater-fed wetlands with shallow water tables were utilized for rice production (with water tables managed in some cases for other crops) but this is now limited by the Ministry of Water, Lands and Environment (MWLE) in recognition of the ecosystem services and biodiversity value of wetlands.

Agricultural use of groundwater in Uganda is predominantly for the watering of livestock. However, figures which quantify this supply are very limited. According to MWLE figures (MWLE, 2006), approximately 20 deep boreholes, yielding an average of 8 m^3 hr^{-1}, have been

constructed and installed with pumping windmills for livestock watering in northeastern Uganda. There is very little evidence of the utilization of groundwater to irrigate fodder crops or crop with residue used as animal feed, which would otherwise constitute the largest part of livestock water demand.

Ethiopia

Throughout the Ethiopian BNB groundwater is the most common source of domestic water, supplying at least 70 per cent of the population. In the rugged mountainous region of the Ethiopian Highlands settlement patterns of rural communities are determined largely by the distribution of springs. The depth to water table in most highland plains is less than 30 m. In the alluvial plains and narrow zones close to river beds, depth to the static water level in the unconfined aquifers does not normally exceed 10 m. These aquifers are the most commonly utilized water source for rural communities. In both cases, seasonal water table fluctuation is not thought to exceed 2 m (Ayenew *et al.*, 2008). Groundwater for domestic use is commonly utilized via springs, shallow hand-dug wells, sometimes fitted with manual pumps, and in some cases, boreholes. In urban centres deep boreholes normally provide water for both drinking and industrial purposes. Over 70 per cent of the large towns in the basin depend on intermediate to deep boreholes fitted with submersible pumps and in some cases, large fault-controlled high discharge springs.

Generally, groundwater quality is naturally good and suitable for multiple uses throughout the BNB. There are some naturally occurring areas of high total dissolved solids and locally high salinity, sulphides, metals and arsenic, but the main concerns for water quality are fluoride, iodine and man-made, point source pollution including nitrates and coliform bacteria.

Despite the importance of groundwater to the majority of the population, it was given very limited attention in planning and legislation in the past, although this is now changing. The demand for domestic water supply from groundwater has been increasingly achieved over the last two decades but will continue to increase and plans to expand access are ongoing (Table 10.3).

Table 10.3 Estimate of rural population supplied with domestic water from groundwater in Ethiopia: 2008 figures and planned improvements to be implemented by 2012

	Region					*National*
	Tigray	*Gambella*	*Benishangul Gumuz*	*Amhara*	*Oromia*	
Population in 2007 (million)[1]	4.3	0.31	0.67	17.2	27.2	74
Population supplied from groundwater (million)[2]	2.05	0.1	0.26	8.6	12.6	34.4
Percentage of population supplied[2]	58	39	44	56	51	54
Percentage supply planned for 2012[2]	109	94	89	118	95	100
Number of groundwater schemes planned 2009–12[2]	7928	610	1428	37,468	26,093	110,460

Sources: [1]2007 National Census, CSA/UNFPA, 2008; [2]MWR/GW-MATE, 2011

Currently, direct groundwater utilization for irrigated agriculture is marginal. This mostly takes the form of shallow wells close to rivers, and in some cases, downstream of micro-dams and sand dams, constructed to effectively recharge groundwater. Generally, a well yield of 2 l s^{-1} is considered adequate to irrigate one hectare. This is mostly supplemental irrigation of cash crops. While surface water irrigation is more common, the groundwater baseflow contribution to river flow should not be ignored. This component is significant and, without it, abstraction for irrigation, especially supplemental irrigation in dry periods, would be impossible. There is some extraction of groundwater for commercial horticulture and fruit production but as these wells are privately managed and largely unregulated, it is difficult to estimate their contribution. Groundwater pumping for commercial agriculture is likely to increase in the future, especially close to urban centres, such as the areas around Addis Ababa, where demand for fresh vegetables all year-round can be satisfied using groundwater and growing more sensitive crops inside (in greenhouses/polytunnels).

Groundwater is essential for livestock production in Ethiopia, primarily for drinking as opposed to feed or forage production. Farmers and pastoralists access groundwater all year-round to water livestock. When this is combined with domestic access, contamination of human drinking water with coliform bacteria is common. Outside of the Nile Basin, the 'singing wells' of the Borena people, pastoralists in southern Ethiopia, are one well-known example of shallow hand-dug wells (<10 m) where water is lifted by hand on a series of ladders, into livestock watering troughs.

A significant number of industrial sectors in Ethiopia rely on groundwater. Ethiopia has several bottled water producers, including naturally carbonated mineral water drawn from the Antalolimestones in the Takeze Basin of Tigray. In general the beverage industry, food processing, textile and garment, and cement producers are heavily reliant upon groundwater. The expanding mineral exploration sector requires significant access to water (both mining and opencast workings), and with prospecting ongoing, there is significant potential for further growth in groundwater demand. The construction 'boom' in many urban areas of Ethiopia also poses a major strain on current 'domestic' supplies: whether domestic supply is drawn from ground or surface water, the construction industry uses (and wastes) vast amounts of water, *causing a significant stress on the existing domestic network. The growth in urban populations and migration to towns and cities, in many cases driving the construction boom, must be met* by expansion in domestic water supply from groundwater (see 'Policy' section).

Sudan (North and South)

The Nile Basin drainage encompasses most of the major groundwater basins of North and South Sudan with total groundwater storage estimated at around 16,000 billion m^3. A range of values can be found for annual abstraction rates (Ibrahim, 2010), from 1 billion m^3 to more than double this when agricultural and domestic uses are combined. Annual recharge is estimated at around 2.3 billion m^3. Throughout Sudan, groundwater is accessed for drinking and domestic water supplies. While 70 per cent of groundwater abstraction in Sudan is reported to be for irrigation, groundwater constitutes around 50 per cent of urban and 80 per cent of rural domestic water supply (Ibrahim, 2010). At the time of writing, North and South Sudan have just undergone a process of separation after years of civil war. While government structures remain in place in North Sudan, and new Ministries are evolving in South Sudan, it is very difficult to access official 'government' figures externally, and most figures which can be accessed are in an unpublished form. Much of the recent published information relates to aid and donor missions, with a particular focus on water supply (e.g. Michael and Gray, 2005; Pact,

2008). Where data exist there are a number of discrepancies in reported figures and conflicting sources of information. For example, rural domestic water supply from groundwater was estimated at 63 million m^3 yr^{-1} in 2002 (including livestock; Omer, 2002) to 300 million m^3 yr^{-1} in 2010 (Ibrahim, 2010; Table 10.4), constituting a rise of 500 per cent at a time when the country was subject to severe conflict, which would naturally limit development.

The Nubian aquifers, underlying the Sudanese Nile, are generally considered to contain good-quality groundwater for all uses: the NSAS, Umm Ruwaba sediments, basement complex, the Gezira sands and gravels and alluvial formations are all important sources of both drinking and irrigation water, with the exception of a few saline pockets. The main constraint to supply of adequate safe drinking water is lack of management and provision of infrastructure, with under-investment and symptomatic poverty still obstructing water supply throughout Sudan. There are a number of historical conflicts over water and water supply points, which continue to be an issue, especially in rural areas (e.g. Darfur and Abyei regions).

Reliance on groundwater for domestic water supply, illustrated in Table 10.4, is likely to be an underestimate as many traditional or informal methods can go unrecorded. Domestic wells range in design and level of technology from simple holes in or close to banks of seasonal streams, lined with grass or tree branches, open large-diameter hand-dug wells lined with brick or concrete slabs, slim low-depth boreholes fitted with hand-pumps or electrical submersible pumps, to deep boreholes fitted with pumps. Even the more formal methods of abstraction can go unrecorded.

Table 10.4 Groundwater utilization for domestic supply throughout North and South Sudan

Region	*Urban (%)*	*Rural (%)*
Khartoum	50	90
Northern	50	60
Eastern	70	90
Central	50	60
Kordofan	60	70
Darfur	70	80
South Sudan	10	100
Average	51	79
Total supply (million m^3 yr^{-1})	800	300

Source: Ibrahim, 2009

Groundwater is essential for agriculture in Sudan. According to the Ministry of Irrigation and Water Resources, around 875 million m^3 are utilized annually for irrigation. The fertile soils found along the Nile floodplain and seasonal streams are irrigated using both the Nile surface water and groundwater. Groundwater is used to irrigate fruit and vegetables via a range of abstraction methods. Where individual plots do not exceed 4.2 ha, hand-dug wells or '*matars*' (hand-dug wells with pipes driven in) fitted with centrifugal pumps are common. Most plots are associated with fertile and easily cultivated floodplains with shallow, annually replenished water tables and low construction costs. Boreholes are also used for irrigation in some areas, either exclusively or to supplement surface water and rainwater.

There are numerous methods of groundwater abstraction in Sudan, determined mostly by the depth to water level, intended use, access to main electric supply and resources available. In rural areas open hand-dug wells are common, with water drawn by a rope-and-bucket system by hand, animal-power or windlass depending on depth. Technologies in drilled wells for domestic or agricultural use range from reciprocating hand-pumps, centrifugal pumps driven by electrical motors or diesel engines and electrical submersible diesel-engine-driven vertical turbine pumps.

Livestock contribute a significant additional agricultural water demand, particularly in less-fertile areas away from river valleys. The livestock population is estimated at around 140 million head (compared with a population of 45 million) concentrated mainly in southern, central and western Sudan, and annual groundwater abstracted for livestock watering is estimated at 400 million m^3. Groundwater also contributes to livestock water demand through production of fodder crops and crop residue for feed.

Table 10.5 illustrates the distribution of abstraction rates and well type in different areas irrigated with groundwater in both North and South Sudan.

Table 10.5 Areas irrigated with groundwater in North and South Sudan

State	*Locality*	*Area (ha)*	*Abstraction (million m^3 yr^{-1})*	*Well type*
Northern	El Seleim	20,000	345	Matar
Northern	Lat'ti Basin	5000	115	Matar
Nile	Lower Atbara Basin	1430	40	Matar
Kassala	Gash Basin	6200	145	Matar + borehole
Gezira	North Gezira	1500	40	Matar + borehole
Khartoum	Khartoum area	5000	120	Matar + borehole
North Kordofan	Bara area	1430	8	Hand-dug
North Kordofan	Khor Abu Habil	1400	5	Hand-dug
South Kordofan	Abu Gebeiha	4000	7	Hand-dug
South Kordofan	Abu Kershola	1000	3	Hand-dug
Greater Darfur	W. Azoum	3000	10	Matar + borehole
Greater Darfur	Jebel Marra area	2900	15	Hand-dug
North Darfur	Kabkabiya	1430	5	Matar
North Darfur	Wadi Kutum	1400	5	Matar
West Darfur	Wadi Geneina	950	5	Matar
South Darfur	Wadi Nyala	1400	8	Matar + borehole
Total		58,040	876	

Source: Ibrahim, 2009

North and South Sudan combined are estimated to have approximately 82 million ha of land suitable for arable production (one-third of the total combined area), of which around 21 per cent is currently under cultivation. In addition to the irrigated areas included in Table 10.5, 1.4 million ha of agricultural land across North and South Sudan were classified by the previous government as eligible for supplementary or complete irrigation by groundwater. Given that only 0.06 million ha out of 82 million ha of suitable arable land seem to be irrigated with

groundwater currently, it is likely that, at some point in the near future, resources will be found to develop this resource and groundwater abstraction will increase significantly. A number of schemes were planned in the 1990s to produce food for export to Gulf states, and with the end to civil war, it is likely that such ventures will once more become viable.

Egypt

Currently, the total annual water requirement of all socio-economic sectors in Egypt is estimated to be 76 billion m^3 yr^{-1}, of which the agriculture sector alone requires 82 per cent (Attia, 2002). Egypt relies heavily on surface water from the Nile, with an annual quota of 55.5 billion m^3 yr^{-1} allocated according to the 1959 agreement between Egypt and Sudan. The total harvestable national run-off is around 1.3 billion m^3 yr^{-1} and the remainder of the demand must be satisfied by using groundwater. The two most important groundwater aquifers are the NSAS of the Western Desert, and Nile Valley and Delta system. The deep and non-renewable fossil water of the NSAS covers about 65 per cent of Egypt and extends into Libya, Sudan and Chad.

Clearly, Egypt's demand already exceeds its apparent supply and this is likely to be exacerbated in the future with increasing demand for expanding agriculture, population growth, urbanization and higher living standards. As the volume of surface water from the Nile cannot be guaranteed with shifting regional politics and uncertainties, groundwater exploitation will undoubtedly accelerate.

There are known to be more than 31,410 productive deep wells and 1722 observation wells distributed throughout the Nile Delta, Nile Valley, coastal zone, oases and Darb El Arbain, and Eastern Oweinat. These include wells for domestic and agricultural supply. Tables 10.6 and 10.7 illustrate extraction rates, use and potential, and distribution of wells.

Table 10.6 Current and potential groundwater use in the Egyptian Nile River Basin (2004 and 2010 values)

Location	*Production wells*[1]	*Abstraction (million m^3 yr^{-1})*	*Observation wells*[1]	*Potential (million m^3 yr^{-1})*
Northern West Coastal Zone and Siwa[2]	1000	149	1	194
Nile Delta and Nile Valley	27,300	5	1704	500
Zone of Lake Nasser	–	0.05	–	20
Western Desert, Oases and Darb El Arbain[2]	3100	1108	13	2246
Eastern Oweinat[2]	50	390	4	1210
Toshka[2]	–	59	–	101
Total		1711.05		4271

Sources: [1]Hefny and Sahta, 2004; [2]MWRI, 2010

Generally, domestic water is obtained from deep wells (>800 m) of naturally good quality. In urban areas, all houses are connected to a mains supply, while around 40 per cent of rural communities are reported to be connected, but large portions of the rural population still depend on water collected from small waterways. Small-capacity private wells are also common at the household level although many are in a poor condition. In the newly settled areas, most

wells are managed by the Ministry of Housing and New Communities or are under the local unities in old towns and villages.

The 82 per cent of Egypt's water demand required for agriculture refers to the irrigation of existing cultivated areas, newly irrigated land reclaimed from the desert, and improved drainage and irrigation conditions. While approximately 70 per cent of this demand is satisfied by surface water diverted in the Nile Valley, the contribution from groundwater is most commonly on the fringes of, or outside of, irrigation project command areas. Around 25 per cent of the total volume allocated to irrigation is thought to contribute to return flow and groundwater recharge via agricultural drainage and deep percolation. Management of groundwater is often fragmented among different stakeholders which may include government agencies, NGOs, farmer organizations, the private sector and investors, depending on the scale of the project. In the newly settled areas around oases and other depressions in the desert, the water supply systems on a subregional and local level include *mesqas* (small/tertiary canals used for water supply and irrigation), wells (government and private), collectors and field drains.

In the newly settled areas of the Western Desert (west of the Nile), agriculture is mainly dependent on groundwater abstracted through deep wells from the NSAS. Shallow aquifers in the mid- and southern desert are contiguous with the deep aquifer providing potential for further groundwater development, and there are plans to expand agricultural land around oases in the western desert with irrigation from both shallow and deep wells. The main obstacles to utilizing this resource are the great depths to the aquifer (up to 1500 m in some areas), and deteriorating water quality at increasing depths. While development of groundwater in the NSAS is naturally limited by pumping costs and economies of scale, there are also transboundary considerations for this shared resource. This is formalized in a multilateral agreement between Egypt, Libya, Sudan and Chad, and an extensive monitoring network exists (see below).

The shallow aquifer of the Nile Valley and Delta is considered nationally as a renewable water source with extraction largely from shallow wells with a relatively low pumping cost. This aquifer is considered as a reservoir in the Nile River system by the Ministry of Water Resources, with a large capacity but with a rechargeable live storage of only 7.5 billion m^3 yr^{-1}. The current abstraction from this aquifer is estimated at 7.0 billion m^3 in 2009 (MWRI, 2010). Conjunctive use of surface water and groundwater is practised widely by farmers, especially during periods of peak irrigation demand and at the fringes of the surface water irrigation network, where groundwater can be the only source. In the Nile Delta areas, a distinction is made between 'old' and 'new' lands facing a shortage of irrigation water. In the old land, the main source of irrigation water is the Nile River but towards the end of irrigation canals, groundwater is in many cases the only source. As the shallow aquifer is in hydraulic contact with both the surface water irrigation system and the Nile River system, it can receive both recharge and pollution from surface water sources and is therefore vulnerable. The aquifer is also affected by programmes which reduce conveyance losses in waterways.

In the Eastern Desert (between the east bank of the Nile and the Red Sea) most groundwater development is confined to shallow wells within wadi aquifer systems and to desalination of groundwater. Total groundwater usage was estimated to be 5 million m^3 yr^{-1} in 1984 and the current extraction rate is likely to be closer to 8 million m^3 yr^{-1}. Potential for further development is largely based on deep wells (200–500 m), accessing the NSAS and large wadis of the Nile Valley and Lake Nasser catchments. There is also some potential for development of brackish groundwater, especially in the Red Sea coastal areas.

In addition to agricultural and domestic use, industry in Egypt is also highly dependent on groundwater. Factories may receive water from mains water supply system or their own wells. A few small factories may depend on surface water from mesqas. The tourism sector generally

depends on a mains supply from the government system; private wells also exist along with desalination plants in coastal zones for both groundwater and sea water purification.

Monitoring and assessment of groundwater resources

The major shortcomings associated with groundwater monitoring systems in the NRB are symptomatic of much of Africa as a whole (Foster *et al.*, 2008; Adelana, 2009) and can be summarized as follows:

- Lack of a clear institutional/legal base and fragmented organizational responsibilities.
- Inadequate technical capacity and expertise, and lack of sustainable financing and resources to monitor and manage groundwater.
- Poorly coordinated groundwater development activities with little or no linkage to groundwater monitoring systems, and database management and retrieval systems.

As noted above, knowledge and data on groundwater use vary widely within the Nile countries but, in general, more information tends to be available in those countries which rely heavily on groundwater. All countries of the Nile are trying to improve their management of groundwater and this requires mapping of aquifers, groundwater monitoring, analysis of extraction and recharge rates, and proper data management. National efforts are also broadly supported by the research, NGO and donor community. The Groundwater Management Advisory Team (GW-MATE) of the World Bank Water Partnership Program has provided technical support throughout Africa over the last decade, and continues to do so, with very positive results (Tuinhof *et al.*, 2011).

Despite the heavy reliance on groundwater for domestic supplies in Uganda, there is no national monitoring network in place, and this is needed as a matter of priority.

Throughout Ethiopia, relatively extensive hydrogeological field surveys provide sufficient information to classify the major aquifers and their characteristics (Ayenew *et al.*, 2008). The Ministry of Water and Energy is now compiling an integrated database, the National Groundwater Information System (NGIS), which will replace the earlier ENGDA (Ethiopian National Groundwater Database) system hosted by the Ethiopian Geological Survey (EGS) and Addis Ababa University. Recent well-drilling campaigns for water in the Addis Ababa vicinity have revealed highly productive deep aquifers at more than 300 m and, in a number of cases, recent wells drilled up to 500 m have revealed highly productive artesian aquifers. It is likely that the aquifers close to urban and more developed areas, such as those near Addis Ababa, will be developed for agriculture and industrial uses in the near future. In some areas such as Gonder and Mekele over-extraction has already led to decline of the groundwater level (Ayenew *et al.*, 2008). Careful monitoring and regulation are needed to prevent long-term negative impacts on groundwater resources by the inevitable expansion of groundwater utilization in the basin.

There is no systematic monitoring of groundwater recharge in Sudan. Localized investigations are usually performed on a case by case basis for a limited time period. Plans have been made for a nationwide observation network but they have not been implemented so far mainly due to lack of funding, coordination and recent civil unrest. Apart from urban centres, abstraction data are estimated and do not account for the numerous traditional wells. Therefore, actual abstraction is likely to be higher than the estimated volumes.

Egypt has a highly developed groundwater extraction network, and data on the distribution of wells have been compiled by several agencies over the past two decades, including the Ministry of Water Resources and Irrigation (Ramy *et al.*, 2008; Table 10.6).

Policy, regulation and institutional arrangements for groundwater resource management

The development of policies and the design of regulations and institutional arrangements are the first steps to managing and regulating groundwater. From this perspective of the Nile countries we have considered in this chapter, all have initiated this process to either a greater or lesser extent, broadly in line with their general level of economic development. The governments of Uganda and Ethiopia have a strong focus on domestic supply from groundwater as a most urgent concern, and are pushing ahead with policies expanding this service in both rural and urban areas, while Egypt has a well-established groundwater-fed domestic water supply system with associated regulation at different local levels, and plans for development and expansion of settlements which rely on conjunctive use of groundwater and surface water. In comparison, prior to separation, Sudan had established mandates for water policy generally, but to date in post-separation Sudan, especially South Sudan, there is no clear framework, with groundwater exploitation occurring on an ad-hoc and completely unregulated basis. Development organizations are also involved in the creation of frameworks for groundwater regulation and management to varying degrees across the NRB, and it is difficult to know the extent to which these frameworks are currently implemented (see section on Ethiopia below). As the countries we have considered are at quite different levels of policy development and implementation, more detail is provided below.

Uganda

Most groundwater utilization in Uganda is for domestic demand in both rural and urban areas. The Government of Uganda views the water sector as vital for poverty eradication, and by working with a number of development partners, it has set a target of providing safe water and sanitation for the entire population by 2025. Currently, water supply and sanitation rates for rural populations are 63 and 58 per cent, and for urban dwellers 68 and 60 per cent, respectively. Groundwater development is key to achieving this target and in the 1990s this began with the formation of the Rural Towns and Sanitation Programme, supported by the World Bank. The Ministry of Water and Environment implements this programme which is ongoing and has a high success rate in providing communities with domestic water from groundwater. Under this initiative 60 urban centres were identified for piped water supply (MWLE, 2006). By July 2006, 180 small towns had been included in the scheme for piped water supply. By that time 98 had functional water supply systems, 24 were under construction and 44 were at the design stage (MWLE, 2006). Out of the 98 operational water supply systems, 73 were based on groundwater from a total of 66 deep boreholes and 24 springs. At that time a further 684 small towns were identified to be provided with piped water during the next 15-year period, of which it is estimated that over 550 will be based on groundwater from deep boreholes (MWLE, 2006). The MWLE also regulates groundwater-fed wetlands and prevents destruction of habitat by conversion to agricultural land.

Ethiopia

In the past there was little recognition of the importance of groundwater in Ethiopia. The existing river basin master plans for example, which were developed for all the major basins of Ethiopia, include very limited groundwater data sets or analyses. However, recognition of groundwater is growing, and the Government of Ethiopia has determined to provide domestic

water supply to 70 per cent of its population by 2015 as a key millennium development goal, primarily based on development of its groundwater resources (see Table 10.3). Working with GW-MATE, the Ministry of Water and Energy has developed its Strategic Framework for Managed Groundwater Development (MWR/GW-MATE, 2011). The framework aims to build an enabling environment with policy adjustments, regulatory provisions and user engagement, so that effective measures can be taken in managing groundwater quality, and promoting demand-side as well as supply-side management. Within this framework action plans will be developed according to national and local priorities within the 'resource setting' (hydrogeological and socioeconomic) and using a range of management tools. At this stage the first action plan has been developed for the Addis Ababa region (MWR/GW-MATE, 2011). The government also recognizes groundwater as a key instrument for economic growth and livelihood enhancement, with groundwater a major component in the ambitious target to increase the area under irrigation by six-fold by 2015 (MWR/GW-MATE, 2011).

According to the MWR/GW-MATE report, the most pressing policy issues are a stronger integration of groundwater development and land use planning, selection of target areas for intense groundwater development and combining groundwater development (both recharge, retention and reuse) with other water resource programmes, including watershed programmes, drainage, and floodplain development (MWR/GW-MATE, 2011). The framework highlights target areas with proven high reserves, high-potential areas with the most accessible aquifers and areas where climate change predictions indicate the need for supplementary irrigation. The MWR/GW-MATE report acknowledges the need to scale up regulation of groundwater, clarifying responsibilities and mandates of different organizations from federal and regional to river-basin level in the private and public sectors, to include the wide range of stakeholders involved in managed groundwater development. Currently, regulations exist but are rarely enforced, and mandates seem to overlap. The 1960 Civil Code established that groundwater is public property and strictly limits the development of private wells while the 1999 Water Resource Planning Policy provides a set of guidelines for water resources development. These regulations need to be enforced by an organization with a clear mandate, and individual cases should be incorporated within a broader development plan, locally and regionally. There is considerable scope for sustainable development of the resource in Ethiopia if the management measures included in Table 10.7 can be implemented.

Stakeholder participation, capacity-building and the promotion of private-sector capacity in addition to capacity within government departments are key to achieving all of the above institutional and non-institutional targets.

Sudan (North and South)

It is difficult to talk about groundwater policy and regulation without considering recent political events and the formation of two separate states of North and South Sudan in July 2011. Prior to separation there were four levels of government in Sudan (interim constitution 2005), all of which had water-policy making mandates:

1. The Federal (National Unity) Government with one ministry for water affairs and a draft water policy.
2. The Government of South Sudan (GOSS) with an approved water policy and three water affairs ministries.
3. The 26 State Governments each with, at least, two water affairs ministries.
4. The Local '*Magalia*' or council level.

Table 10.7 Proposed institutional responsibilities for the development and management of groundwater resources in Ethiopia

Institution	*Responsibility/Activity/Mandate*
Ministry of Water and Energy	Develop policies, standards and criteria for groundwater management plans, drilling standards and well designs, fluoride/iodine treatment; maintain information base, initiate and support interregional groundwater management plans and oversee water allocation
Ethiopian Geological Survey	Plan and guide groundwater assessments
Federal Environment Protection Authority (EPA)	Review possible impacts of national investments on groundwater quality and quantity; strategic environmental assessments linked to groundwater management plans
Regional governments	Integrate groundwater management into other development programmes
Regional Water Resources Development Bureaus	Adopt policies, standards and criteria; initiate groundwater management plans for selected areas and supervise quality of monitoring; licensing in low-density areas
Regional EPAs	Licensing in high-density areas (need to be upgraded); and review possible impacts of investments on groundwater quality and quantity
River Basin Organizations (need to be created)	Coordinate surface water and groundwater allocation and supply
Water user associations (need to be created)	Local regulation and efficiency measures; support and engagement in groundwater management plans
Well field operators	Monitoring
Universities management	Courses in drilling, drilling supervision and groundwater
Technical and vocational education and training (TVETs), NGOs	Courses in manual drilling and pump development
Private-sector educational services	Specialist courses
Public-sector technical services	Design and supervision
Private-sector technical services	Design and supervision
Corporate private-sector drilling services	Drilling of shallow and deep wells (to be strengthened)
Artisanal private-sector drilling services	Drilling development of very shallow wells (to be strengthened)

Source: MWR/GW-MATE (2011)

Almost all the levels had identical empowerment but no institutional capacity, resulting in general confusion and widespread infringements of existing principles. Therefore, the Water Resources Act was passed in 1995 but remains unimplemented to date. This situation is further complicated by the recent formation of two states. The reinstitution of a legal framework is yet to be implemented and currently the development of groundwater resources in Sudan remains unregulated. Wells are drilled without permits or regulation, often close to septic pits dug for

the disposal of household sewage, and there is no accountability for any negative impact on the groundwater resources.

A further and major challenge faced by regulation of groundwater in North and South Sudan is the lack of accurate information on groundwater potential and the absence of quantitative and qualitative monitoring. The institution responsible for this (in the pre-separation Sudan) was an under-resourced, small department of the Ministry of Irrigation and Water Resources, mandated to provide both water resource management and water services. Almost the entire ministry budget is required to deliver irrigation and drinking water services. The significant potential for groundwater development is recognized regionally and there has been interest in investing in groundwater irrigation in the Nile, Northern, Central and Khartoum States, particularly from the Gulf States, but lack of coordination and clear regulation at this point has the potential to cause further conflicts.

Egypt

The challenge of managing scarce water resources, including groundwater, for sustainable development incorporating medium and long-term use for a range of stakeholders is recognized as priority by the Egyptian government. In most water resources management situations, some form of planning already exists, varying according to the resources in question, planning tradition, administrative structure and technical issues. The Ministry of Water Resources and Irrigation (MWRI) has a management plan which aims to address the challenges of water scarcity it considers to be of concern. In relation to groundwater, the plan highlights groundwater development for agricultural expansion into 'new' areas, relocating people from the Nile Valley and Delta to initiate new communities in areas currently desert. This will clearly intensify demands on groundwater.

In the 'Renewable Aquifer Underlying the Nile Valley and Delta' the MWRI plan focuses on the conjunctive use of surface water and groundwater by:

1. Utilizing aquifer storage to supplement surface water during peak periods and artificially recharging the groundwater during the minimum demand periods.
2. Employing sprinkler or drip irrigation from groundwater in the 'new lands' to prevent waterlogging and rising water tables.
3. The use of vertical well drainage systems in Upper Egypt to prevent waterlogging and rising water tables.
4. Utilizing groundwater for artificial fish ponds (high quality and consistent temperature).
5. Pumping groundwater from low-capacity private wells at the end of long *mesqas* to supplement canal water supply.

In the deep aquifers of the Western Desert (and Sinai), which require a large investment to be viable, future strategies outlined in the plan include:

1. Intensive survey to determine the main characteristics of each aquifer including its maximum capacity and safe yield, and monitoring to prevent abstraction beyond sustainable yields.
2. The development of new small communities in the desert areas designed to use all available natural resources through integrated planning.
3. Utilizing renewable energy sources, including solar and wind, to minimize the pumping costs.

4. Application of new irrigation technologies in desert areas minimizing losses, especially deep percolation due to the high porosity.

If implemented, all of these strategies would help to reduce pressure on increasing demand for groundwater. However, at this stage the plan is on paper and subject to investment finance.

The Egyptian government is also considering the use of the brackish groundwater (3000–12,000 mg l^{-1} TDS), such as is found at shallow depths in the Western and Eastern Deserts and at the fringes of the Nile Valley following desalination treatment. Renewable energy sources are proposed to reduce the cost of the treatment process, with the resulting 'fresh' water used for supplemental irrigation of a second-season crop.

Overall, future strategies and policies for groundwater development assessment and utilization identified by the MWRI plan include:

1. Utilization of technologies from the water resources management sector, especially remote sensing and GPS techniques; numerical modelling of groundwater and surface water models; information and decision support systems to integrate the ministry's water resources information; use of geophysical methods (e.g. electromagnetic and electrical resistivity, and use of environmental isotopes).
2. Water quality monitoring and management to prevent transport and contamination by pollutants.
3. Raising awareness with the general population and with policy-makers, of water resource issues and achievements in water management, via the media and by demonstration of positive water saving consequences; achieving public participation and commitment of policy-makers to water policies and programmes; increasing knowledge and capacity on new technologies to conserve water in irrigation and domestic use.
4. Continuous monitoring and evaluation to enable strategic adjustments needed to correct deviations from the original objectives.
5. Coordinating and enabling different water users and water-user groups.
6. Institution building and strengthening, linking the public and private sectors, transferring knowledge and human resources within the water sector; providing management training and technical skills.
7. Strengthening coordination between ministries to avoid overlapping mandates, and enhance exchange of data, knowledge, experience and technical expertise in the different fields of water resources between different authorities.
8. Providing a detailed review of all existing water resources laws and decrees and their relation to water management to ensure that up to date laws and regulations reflect the long-term objectives of water resources management.
9. International cooperation – in the case of groundwater this particularly refers to the NSAS, shared by Chad, Egypt, Libya and Sudan.
10. Ensuring that the planning and policy formulation process is based on the most up to date research and development outcomes and comprehensive planning studies.

Overall and individually, these strategies are highly desirable for the sustainability of the groundwater resources. It can only be hoped that the plans can be implemented.

In considering the information provided above, it is useful to note that the groundwater resources of the NRB, like the river itself, do not conform to national and other political boundaries. Wise management of groundwater requires governments and related agencies to work together to achieve sustainable utilization of this often shared resource.

Conclusions

Large parts of the NRB are prone to high rainfall variability and seasonal and periodic droughts. Further, climate change predictions indicate that this situation may worsen. It is broadly accepted that groundwater can provide some degree of buffering to this threat, supplementing surface water supplies, reducing risk and strengthening resilience, and reducing the vulnerability of the poor to water shortages. In fact, adequate reliable water supplies are essential to economic development at all levels. It is increasingly acknowledged that wise management of groundwater resources can provide this security. In addition, increasing water stored in this reserve during times of high rainfall by actively diverting surface water to groundwater recharge can support sustainable groundwater use.

There are many challenges facing sustainable management of the groundwater resources of the NRB. With the exception of Egypt, most of the ten countries are relatively undeveloped in terms of industry and commercial agriculture and the role of groundwater is primarily for the provision of domestic supplies. This will change in the future, and so the demand for water from groundwater for these uses will increase. Africa's population is growing rapidly and the 1999 population of 767 million is projected to nearly double by 2035 (UNFPA, 2011). Although fertility rates do differ across the continent, these predictions are largely applicable to the NRB, with obvious implications for domestic use, the consumption of water for increased food-agriculture demand, and all other high-water-demand and human-related activities. In parts of the basin where surface waters are already severely stressed, such as Egypt, growing populations pose a severe challenge for groundwater management. In Egypt's case, the authorities are already relying strongly on groundwater to meet the needs of new communities in marginal areas and to relieve pressure on surface water in more densely populated areas close to the Nile River.

In parallel to industrial and commercial development, the building and strengthening of governance and regulatory structures are also in an early stage of development in many Nile countries. Generally, natural resources policies and regulations can be seen to lag behind other sectors (such as law and health). Many countries have developed policies and strategic frameworks, often with outside help (e.g. Ethiopia and GW-MATE), but implementing the policies may take several more years. Naturally, without clear mandates and regulatory structures, monitoring and planning cannot be well implemented. While the importance of sustainable management of groundwater is now broadly acknowledged within the NRB, conjunctive management of groundwater and surface waters is some way off.

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