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Review article

Groundwater potential and sustainable management in the Nile valley: an overview

Abdeen Mustafa Omer*
Nottingham, Nottinghamshire, UK.

*Corresponding author; Nottingham, Nottinghamshire, UK.

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A B S T R A C T

Sudan is dependent upon groundwater aquifers for its supply of water, both for human consumption and irrigation. The present minimum annual requirements of water for human and animal consumption in the rural areas of Sudan are estimated to be 275 x 10^6 m^3 (23% of this amount is provided from groundwater). About 1381 x 10^6 m^3 are estimated to recharge from the major basins annually. Only 143 x 10^6 m^3 of this recharged water is used because of lack of proper policies, technical manpower, inadequacy of knowledge and absence of appropriate research to develop new technologies and approaches. In this chapter the groundwater resources management in Sudan is presented. It can be concluded that the groundwater potentialities of the basins are extremely high. Finally, large quantities of groundwater are available for future development in irrigation and domestic supply.

1. Introduction

Groundwater is the most important resource in Sudan. About 80% of the inhabitants of Sudan depend on groundwater for their living most of the year (Wheater, 2007). In the northern part of the country rain rarely falls and the country is mainly deserted. Apart from the River Nile, the wells are the only sources of water. Southwards a tropical continental type of climate prevails, except in the extreme south, where the climate is described as continental equatorial. Both these climate zones have a distinct dry season (December to June), which increases in intensity and duration northwards (Ali, 2009). The climate in the southwards of Sudan is a typical desert climate where rain is infrequent and annual rainfall is between 75-300 mm (Ali, 2009).

The River Nile and its tributaries are the main sources of water. In addition, the water pools collected in natural depressions are used directly after the rainy season. The annual average rainfall ranges from 1 mm in the northern desert, to 75-300 mm the southwards and 1600 mm in the equatorial region (Omer, 2012). The total annual rainfall estimated at 1093.2×10^9 m^3 (Omer, 2012). When this dries out small-unlined open wells are used for water supply. Open wells are excavated land to store rainwater for use in drought seasons in rural areas to supply water for human use and animal. Wadi is surface area where rainwater is collected in summer. Considering the huge potential of Wadi systems in Sudan and the shallow aquifers underlying them, better knowledge of surface and groundwater interaction is certainly a mandatory prerequisite for sound management of surface and groundwater resources in Wadi systems in many areas of Sudan. Key words that could be mentioned here are conjunctive use of surface and groundwater, water harvesting and management of groundwater recharge. The system of open wells was developed along Wadi beds in alluvial deposits and in the depressions where water is collected during the summer. All the urban and semi-urban systems existing today, which were pasture centres, are found along Wadi courses or natural depressions where water was available and easy to obtain. The number of settlers increased and the need for water was more and more. New local techniques of wells were used with linings of different materials and well depths increased as the water levels began falling. Drilling of wells started in 1919 in El Obeid town with a steam operating percussion rig (Mukhtar, 2008). This was followed by several other wells drilled in different villages to sustain water requirements. Drilling techniques developed, and rotary drilling was introduced in 1958 (Mukhtar, 2008). Well locations and designs became a problem when new locations were needed away from the natural catchments areas (Mukhtar, 2008).

In 1966 the National Rural Water Corporation (NRWC) was established, and the groundwater investigation section was formed. The main water bearing formations in Sudan (Abdel, 1999) include:

1. The Quaternary to recent superficial deposits
2. The Plio-pleistocene Umm Ruwaba formation
3. The Tertiary basalts
4. The Cretaceous Nubian sandstone formation
5. The Weathered basement complex formation

The further development of groundwater for agriculture and domestic use is one of the priorities to improve the agricultural yield of the country and the domestic and industrial demands for water (groundwater needs little treatment). Other factors that should be considered in planning priorities of water demand (type, distribution, and quality), are the availability of alternative resources, the existing development plans, and the sociological conditions and political priorities. Based on them the most important aquifer is the Nubian sandstone formation. It occupies about 29% of the total surface area of Sudan (Shakeel, Jayakumar, and Salih 2008). Fortunately, most of this is situated north of latitude 12° ’N where water is needed most as shown in Figure 1. These different formations constitute the major basins of Sudan, either in a simple form, i.e., one geological formation, or in a complex form, i.e., two or more geological formations. Two of the complex basins are in the Nubian, and basalt formations; and two in the Nubian and Umm Ruwaba formations (WHO, 2006).

Demand for groundwater in many areas of the Sudan has recently increased considerably in order to meet the needs for the implementation of agricultural and economic development plans but regrettably, these developments are taking place in a rather unplanned manner leading to many problems such as overexploitation, reduction of reliable yield, and deterioration of quality. The purpose of this communication is to discuss these challenges in some details and suggest directions for overcoming them. The study also includes the use of advanced methodologies for groundwater management and protection in Sudan.

2. Geology of Sudan

The geological formations as shown in Figure 1, which constitute Sudan, are:

1. The basement complex (Precambrian)
2. The older granites (Lower Palaeozoic)

3. Nawa series (Upper Palaeozoic)
4. The Nubian sandstone formation and the Yirol beds of the south Mesozoic
5. A. Mudic chert (Tertiary)
   B. Younger granites
6. Umm Ruwaba formation
   a. River gravels (Quaternary)
   b. Qoz sand (Sand Dunes), clay plains, and Red sea-terraces and reefs
   c. Nile valley alluvial

The basement complex, which is the oldest rock type in Sudan, includes all the igneous, metamorphic and sedimentary rocks that are overlain by horizontal and sub horizontal Palaeozoic or Mesozoic sedimentary or igneous rocks.

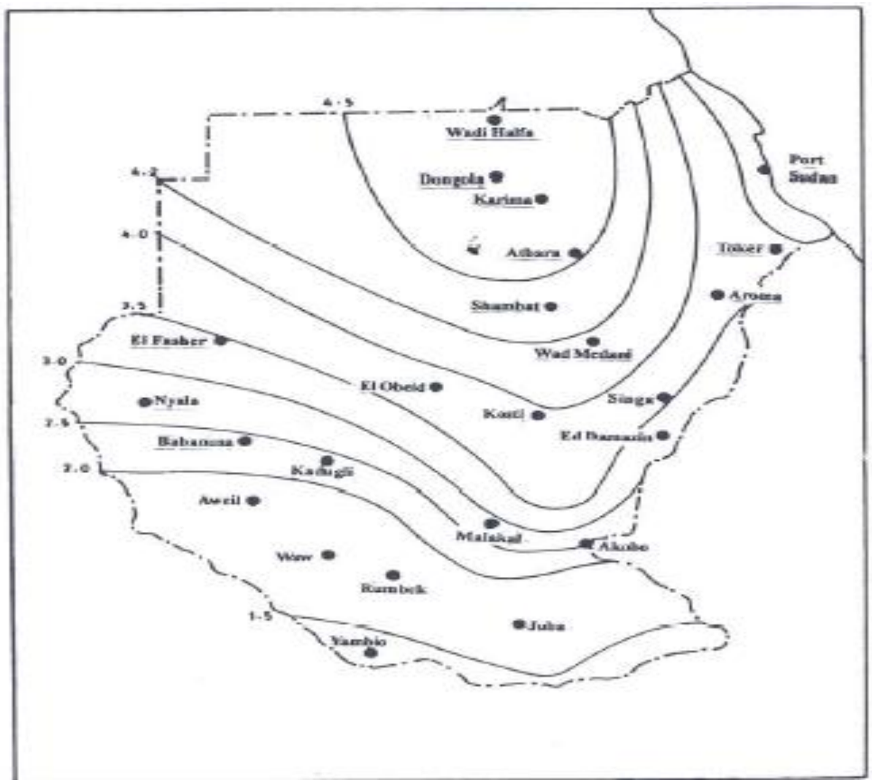

Fig. 1. Metro-geological map of Northern part of Sudan.

3. Groundwater basins

The groundwater basins are either in a simple form or a complex form, according to their geological formation.

3.1. The Nubian basins

3.1.1. Sahara Nile basins

The Nile basins cover the northern part of northern Kordofan state and extend from north of Khartoum to the Egyptian border as shown in Figure 2. It covers an area of 273,980 square kilometres (sq. kms). The geological formations in this area are the Nubian sandstone formation and the basement complex. The groundwater fluctuations, together with the environmental isotopes, indicate that the main source of recharge is from the river Nile together with the underflow from the Blue Nile basins (Salih, 1984). The amount of water recharged annually is estimated to be 136 x 10^6 m^3 (cubic meters). The outflow from this basin is in the northern border of Sudan; this is estimated to be some 7.3 x 10^6 m^3 (Salih, 1984). Three promising areas are recommended for further detailed studies:

1. Wadi El Mugadam
2. Wadi El Qa'ab
3. Wadi El Khuewi and Wadi El Seleim

3.1.2. Sahara Nubian basin

The Sahara Nubian basin covers the northern part of Darfur state. It extends northward from the Tagabo-Meidob up to the Egyptian border, covering an area of 324,656 square kilometres (sq. kms). The geological formations in this region are the Nubian sandstone formation, which covers most of the area, and the basement complex with the tertiary volcanics of Meidob and Tagabo hills. The water levels range from 10-50 m. The water is flowing in two locations:

1. El Natron Oasis
2. Nukheila Oasis

The amount of water recharged annually is estimated to be 20.6 x 10^6 m^3 (Salih, 1984). Wadi Hawar region, which forms the southern margin of the Sahara area, is a promising area for further development and further detailed studies.

Fig. 2. Map of Sudan.

3.2. Central Darfur basin

This basin covers the central part of Darfur state and the western part of northern Kordofan state. It extends southward from the Tagabo-Meidob groundwater divide, and is connected to the Baggara basin in the south. Its surface area is 52,924 square kilometres (sq. kms). The geological units, which form the basin, are the Nubian sandstone formation and the basement complex (Iskander, 1969). The depth of water range from 25-100 m and the groundwater movement is from the north to the southeast, with a velocity of 0.3 to 6.0 m per year (Iskander, 1969). The amount of annual recharge is 47.6 x 10^6 m^3 (Iskander, 1969). Umm Bayaia and Saniya Hayei are two promising areas for further detailed studies and further development.

3.3. Nuhui basin

This basin covers an area of 6,798 square kilometres (sq. kms) in central part of northern Kordofan state. Geologically, it is formed of Nubian sandstone formation, occupying a saddle between the Nuhui uplift in the southwest and the Wadi El Malik-Sodri uplift in the north. The annual recharge is estimated as 15.4 x 10^6 m^3 (SNWP, 2010). The depth of water levels ranges from 75-120 m (SNWP, 2010). The direction of groundwater flow is from the west to the east with a velocity of 1.0 to 2.75 m per year (SNWP, 2010).

3.4. Sag El Na'am basin

This basin covers an area of 2,678 square kilometres (sq. kms), and is connected to central Darfur basin through a narrow straight (Salama, 1971). The depth of water levels ranges from 50-1000 m. The water is under free water table conditions on the fringes of the basin, and in the central part of the basin where the mudstone layer is 16 m (Salama, 1971). The groundwater movement is from the north to the south and southeast, with a velocity ranging from 1.0 m per year in the southern part of the basin, to 25 m per year in the central and southern parts. The exploitation of the basin for irrigation purposes is being developing, due to the deep water levels.

3.5. River Atbara basin

It extends north to Abu Haraf water divide up to the Atbara River, covering an area of 23,896 square kilometres (sq. kms), and is bounded by the River Nile from the west and the basement from the east. The geological formations are mainly the Nubian sandstone formation with the terrace deposits on the riverbanks (Abdelsalam, 1966). The water level ranges from a few meters near the Nile and the River Atbara. The water level drops away from sources or recharge and reaches down 100 m. After the construction of Khashm El Girba dam in the upper part of River Atbara, the flow in the lower part becomes seasonal only during the floods. This greatly affected the life of citizens, and the developments of groundwater resources became a necessary. It is expected that about 4.20 x 10^6 square kilometres (sq. kms) will be irrigated from the groundwater resources.

3.6. Umm Ruwaba basins

3.6.1. Sudd basins

This is the largest basin in Sudan, which covers an area of 365,268 square kilometres (sq. kms) extending from south of Bahr El Arab in a southeast direction down to Juba, and northeast up to Renk. Two major basins are connected to this aquifer and their outflow recharges the basins:

1. The Baggara basin from the western part of Sudan
2. The eastern Kordofan basin from the central part of Sudan

The main geological unit, which forms this basin, is the Umm Ruwaba, which consists of fine sediments. The groundwater in Sudd basin is in a closed basin. The water levels are near to the surface, and they range from 10-25 m (Abdelsalam, 1966). The groundwater movement is towards the central part of the basin. The velocity ranges from 0.1 to 1.8 m per year (Abdelsalam, 1966). The annual recharge is 341 x 10^6 m^3, the amount of water under permanent storage is 11 x 10^9 m^3, and the abstraction rates (surface runoff) are 1.8 x 10^6 m^3 per year (Abdelsalam, 1966).

3.6.2. Western Kordofan basins

The western Kordofan basin covers the central part of northern Kordofan state from north of El Obeid extending in a southeast direction down the White Nile. The surface area of the basin is 68,392 square kilometres (sq. kms). The geological formation is mainly Umm Ruwaba, which is covered by Qoz sand (Sand Dunes). The water levels range from 50-75 m in the northern part of the trough. The water velocity is slow, between 0.1 to 0.3 m per year. The main recharge is from the White Nile, and also from the surface flow during the rainy season. The annual recharge is about 15 x 10^6 m^3, and the basin storage is 1,730 x 10^6 m^3 (Kheiralla, 1967).

3.7. Nubian Umm Ruwaba basin

3.7.1. Baggara basin

This basin covers nearly the whole area of southern Darfur state and the western part of southern Kordofan state. The area is about 141,316 square kilometres (sq. kms). The water levels range from 10-75 m and the deepest water levels are in the central part of the basin. Groundwater is moving from the north, east and west towards the central part of the basin. The annual recharge is 155 x 10^6 m^3. The basin storage is 7,110 x 10^6 m^3 while the abstraction rate (surface runoff) is 11.9 x 10^6 m^3 per year (Kheiralla, 1967).

3.7.2. Blue Nile basin

The Blue Nile basin covers the area between River Rahad and the Blue Nile in the Blue Nile state, extending over an area of 75,808 square kilometres (sq. kms). The geological units which form the Blue Nile basin are the basement complex (Kheiralla, 1967). The water levels range from a few meters near the rivers, to a maximum of 50 m away from the stream. The average velocity is from 1.0-2.5 m per year. The basin storage is 2,270 x 10^6 m^3, and the annual recharge is 70.9 x 10^6 m^3. The areas along the Blue Nile are the most promising for future development.

3.8. The Alluvial basins

The major alluvial basins are seasonal streams (Khors). The runoff in these streams does not exceed three months per year. The runoff during this period is substantial, and the aquifers are completely recharged after the rainy season. The shallow depths enabled the natives to develop their own technology of abstracting water for irrigation purposes. This basin is the oldest known cultivation centre on groundwater resources. Many of alluvial basins are promising future development centres if the infrastructures are developed.

3.9. Nubian Basalt basins

3.9.1. Gedaref basin

The basin covers the central part of Kassala state extending over an area of 28,016 square kilometres (sq. kms). The basin is formed mainly of Nubian sandstone formation and basalts. The water levels range from 50-75 m. The water is moving in a northwest direction. The basins storage is about 700 x 10^6 m^3. The annual recharge is 41.7 x 10^6 m^3, while abstraction rates are 1.2 x 10^6 m^3 per year. The saturated thickness of the aquifer ranges from 200-500 m. The recharge is mainly from the water seeping into mudstone formation from the River Setit (branch from River Atbara). The basin is receiving some underflow from an adjacent basin in the borders; this amount is estimated to be 12 x 10^6 m^3 per year (Omer, 2012).

3.9.2. Shagara basin

Shagara basin is the smallest basin covering an area of 824 square kilometres (sq. kms), west of El Fasher town capital of northern Darfur state. Jebel Marra and Sag El Na'am basin from northwest bound it from the west. This basin is formed geologically of Nubian sandstone formation and basaltic flow in the centre of the basin. Water levels are near the surface, about 25 m; the saturated thickness of the aquifer ranges between 200-300 m. The recharge is from surface flow during the rainy season. The basin storage is 4.5 x 10^6 m^3. The annual recharge is about 1.1 x 10^6 m^3, while the abstraction rates are 0.7 x 10^6 m^3 per year (Omer, 2004).

4. Discussion

Sudan is geo-politically well located, bridging the Arab world to Africa. Its large size and extension from south to north provides for several agro-ecological zones with a variety of climatic conditions, rainfall, soils and vegetation. Water resources available to Sudan from the Nile system, together with groundwater resources, provide a potential for thirty years increase in the irrigated sub-sector. There are also opportunities for increased hydropower generation. The strategy of Sudan at the national level aims at the multi-purpose use of water resources to ensure water security for attaining food security, drinking-water security, fibre-security, hydro-energy security, industrial security, navigation, waste disposal and the security at the regional levels within an environmentally sustainable development context and in harmony with the promotion of basin-wide integrated development of the shared water resources (Noureddine, 1997). The government has continued to pay for the development and operation of water systems, but attempts are being sought to make the user communities pay water charges. In order to ensure the sustainability of water supplies, an adequate institutional and legal framework is needed. Funds must be generated (a) for production, (b) for environmental protection to ensure water quality, and (c) to ensure that water abstraction from groundwater remains below the annual groundwater recharge. The most important research and development policies which have been adopted in different fields of water resources are: (i) the water resource; (ii) irrigation development; (iii) the re-use of drainage water and groundwater; (iv) preventive and canal maintenance; (v) aquatic weed control and river channel development, and (vi) protection plans. The physical and human resources base can provide for sustainable agriculture growth and food security for itself and for others in the region. Failure to do so in the past derives from several causes and constraints, which are manageable. These include misguided policies, poor infrastructure, and low level of technology use, recurring droughts and political instability. Perhaps the biggest challenge is that of finding resources for capital improvements in the light of changing water-quality regulations and ageing systems (James, 1994). Sudan is rich in water (from the Nile system, rainfall and groundwater) and lands resources in Table 1.

Surface water resources are estimated at 84 billion m^3 and the annual rainfall varies from almost nil in the arid hot north to more than 1600 mm in the tropical zone of the south (Omer, 2012). Table 2 shows land use, land-resource zones and water resources of the region. The total quantity of groundwater is estimated to be 260 billion m^3, but only 1% of this amount is being utilised (Omer, 2012). Water-resources assessment in Sudan is not an easy task because of uncertainty of parameters, numerous degrees of freedom of variables, lack of information and inaccurate measurements. However, according to seasonal water availability, Sudan could be globally divided into three zones: (a) areas with water availability throughout the year are the rainy regions (equatorial tropical zones); (b) areas with seasonal water availability; and (c) areas with water deficit throughout the year, which occupy more than half the area of Sudan.

Table 1
Hydrogeological property of groundwater basins in Sudan (Omer, 2012).

Basins	Amount of water recharged (10^6 m^3)	Water level (m)	Aquifer thickness(m)	Velocity (m/year)	Abstraction ($10^6 m^3$/year)
Sahara Nile	136	30-100	300-500	1-2.5	7.3
Sahara Nubian	20.6	10-50	300-500	0.8-1.5	1.5
Central Darfur	47.6	25-100	250-550	0.3-6.0	5.5
Nuhui	15.4	75-120	200-400	1.0-2.75	1.6
Sag El Na'am	13.5	50-1000	300-500	1.0-25.0	2.5
River Atbara	150	100-150	250-300	0.3-5.0	2.3
Sudd	341	10-25	200-400	0.1-1.8	1.8
Western Kordofan	15	50-70	300-500	0.1-0.3	1.7
Baggara	155	10-75	300-500	0.1-2.4	11.9
Blue Nile	70.9	10-50	250-500	0.1-2.5	10.2
The Alluvial	N.A	Shallow	N.A	N.A	N.A
Gedaref	41.7	50-75	200-500	0.1-2.0	1.2
Shagara	1.1	25-30	200-300	0.1-2.5	0.7

N.A Not Available.

Table 2
Land use, land-resource zones and water resources (Omer, 2012).

(a) Land use (x 10^6 hectares)	
Total area	250.6
Water surface	13.0
Cultivated area	8.4
Pastures	29.9
Forests and woodland	108.3
Uncultivated land	81.0
Area under crop irrigated rain-fed mechanised, rain-fed traditional	10.0

(b) Land-resource zones

Zone	Area as % from total area of Sudan	Persons per km^2	Mean average rainfall range (mm)
Desert	44	2	0-200
QOS sands (Sand Dunes)	10	11	200-800
Central clay plains	14	19	200-800
Southern clay plains	12	8	800-900
Ironstone plateau	12	7	800-1400
Hill area and others	8	16	Variable

(c) Water resources

Water resource	Available number	Category water level (m)	Dynamic water level
Haffirs*	824	surface	824
Slow sand filters	128	surface	128
Open shallow wells	3000	0-10	3000
Boreholes deep wells	2259	0-25	1248
		26-50	478
		51-75	287
		76-100	246

* The Haffir is the local name in Sudan for water reservoir. The Haffir is a hollow dug in the ground designed to store water runoff after a rainy season; the Haffir is usually used in semi arid regions where rainfall is annual but over short periods and storage is required for the rest of the year. The Haffir can be natural or manmade, water storage is not a new concept, and however the technology of today can improve the efficiency of the traditional water storing methods. The water is used by all the community, farmers, nomads, livestock and for domestic drinking water.

5. Conclusion

1. Groundwater resource a governing factor in the development of many areas in Sudan. The resources will be used in multi-purposes projects, including: domestic, industrial, irrigation and livestock. The appraisal of groundwater resources is expensive (3500 US$ Dollars per well), and time-consuming procedure if exact quantative estimates are required.
2. About 1,381 x 10^6 m^3 of water is estimated to recharge from the major basins annually. Only 143 x 10^6 m^3 of recharged water is abstracted for different purposes because of lack of appropriate and consistent

policies for groundwater development, shortage of professional and technical manpower and training facilities.

3. Several projects are now developed for the use of groundwater in irrigation. About 1.1 x 10^6 hectares are planned to be irrigated from groundwater.
4. The continuation of the numerous research works is essential for proper utilisation of groundwater resources.
5. The data presented in this paper can be considered as nucleus information for executing research and development of groundwater resources; at the same time, they could determine sites that are likely to have a better prospect.
6. Finally, a data base will be needed to provide all the necessary information for scientific studies regarding water matters.
7. The decision where and how much groundwater to be pumped depends on the quality of groundwater and the depth from which it has been pumped.

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