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Rainwater Harvesting for Urban Areas: a Success Story from Gadarif City in Central Sudan

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Abstract Gadarif city, in central Sudan, has suffered from a shortage of drinking water for decades. Half of its daily water requirement is met through river water imported over 50 km away and from local salty wells. As a consequence of building a small dam to control seasonal floods, it was found that the dam reservoir recharges groundwater, raising the water table by few a meters. Such experience was repeated and a second dam built in response to this success. This indicates that such a method may be a useful rainwater harvesting technique to provide safe water in water deficit areas in semi-arid regions affected by climate change and population increase.

Keywords Rainwater harvesting · Urban water demand · Groundwater increase · Climate change · Sudan

1 Introduction

Gadarif (or Gedaref) city has long suffered from an acute shortage of drinking water. This situation has been aggravated by climate change and a steady increase of population (Table 1). Until the late 1990s, the city depended chiefly on distant sources of water supply. The water is brought through 50 km of pipes from the seasonal River of Atbara. Additional supply comes from bored wells, 10 km away, and local salty hand-dug wells around the city.

In 1995, a small dam, Al-Saraf, was built at *Khor* (stream) Abu Fargha in the vicinity of the city to protect the city from seasonal floods. The water stored behind the dam has infiltrated the soil and consequently raised the water table (Table 2). These results have encouraged the authorities to adopt a strategy of building small

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Table 1 Population of Gadarif city, 1973–2007

Year	Population
1973	66,465
1983	116,876
1993	191,164
2007	354,927

Source: Compiled from World Gazetteer (2007) and City Population (2007) http://www.citypopulation.de/Sudan.html

dams to increase groundwater, and thus to supply additional water to Gadarif city. Accordingly, the small dam of Dalasa II was built in 1998 on *Khor* Magadeem.

1.1 Literature Review

Literature review showed that rainwater harvesting to supply drinking water for urban areas has a long history in semi-arid areas (Abdelkhaleq and Ahmed 2007; Pandey et al. 2003). Building dams to tap stream water, channeled through canals and stored in reservoirs, was practiced by ancient Jordanians about 5,000 years ago to provide drinking water to the old city of Jawa (Abdelkhaleq and Ahmed 2007) and Umm el-Jimal city in the Early Roman period (de Vries 1997). The Nabataeans civilization that emerged in the arid region of southern Jordan more than 2,500 years ago; these people built dams to provide their capital city Petra and other settlements with water for drinking and irrigation (Abdelkhaleq and Ahmed 2007; Oleson 1995).

Check-dams were constructed across seasonal streams in many states in India to make water available for agriculture and domestic use (Balooni et al. 2008). Collection of rainwater through construction of dams to recharge groundwater in semi-arid areas has increased groundwater level in India by 2 m (Raju et al. 2006:527) and in United Arab Emirates by more than 7 m (Murad et al. 2007:1454).

The same technique to increase groundwater for urban areas has largely been used for some time in the arid and semi-arid areas of the Arab world. More than 650 dams were built in Saudi Arabia, Oman, Qatar and United Arab Emirates for protection from flash floods and recharge purposes (Al-Rashed and Sherif 2000; Murad et al. 2007). Al-Turbak (1991) has questioned the effectiveness of recharge from surface reservoir because of the accumulation of silt and high evaporation rates in the dry areas. On the other hand, Al-Muttair and Al-Turbak (1991), Al-Muttair et al. (1994), Sendil et al. (1990) have suggested ways to improve efficiency of reservoir recharge in Saudi Arabia.

Roof catchments is an old method of rainwater harvesting that has widely been used to provide urban dwellers with potable water supply in many parts of the

Table 2 Recent dams of Gadarif city, 1995–2006

Name	Year of construction	Capacity in cubic meters
Al-Saraf	1995	2,000,000
Dalasa II	1998	792,000
Ed Al-Teen	2005	500,000
Al-Sharief	2005	No information
Al-Agib		

Source: Field Survey 2006

developing world (Gould and Nissen-Petersen 1999; Handia et al. 2003; Kumar 2004; Preul 1994; Thomas 1998).

The increase of population and urbanization in developing countries, coupled with the recent evidence of climate change, may result in insufficient water to meet the urban population demand (Murad et al. 2007; O'Hara and Georgakakos 2008; Pandey et al. 2003; Ruth et al. 2007; Wheida and Verhoeven 2007). Therefore, rainwater harvesting is considered crucial for future demand. The mathematics, however, are not favorable: construction of new dams worldwide could increase accessible run-off by about 10% over the next 30 years, whereas the population is projected to increase by more than 45% during the same period (Pandey et al. 2003:54; Postel et al. 1996). The objective of this paper is to examine new means of rainwater harvesting technique to provide an additional source of drinking water to Gadarif city of central Sudan in a changing physical environment associated with urban population growth.

2 Methodology

2.1 Study Area

Gadarif city, the capital of Gadarif state, is located at 14°N and 35°E. (Fig. 1). Gadarif state is one of the Sudan's richest states in animal resources and crop production (Mustafa 2006; Woodward 1990). Yearly precipitation in the state varies between 900 mm in the south and 200 mm in the north. The city receives an average of 600 mm of rainfall annually. To the south, rainfall is sufficient to permit the growth of sorghum and sesame, while the lower rainfall in the north supports only short grasses.

The dominant physical feature of the state is a clay plain, which slopes gently to the west. The clays comprising the plain are dark in color, alkaline and have

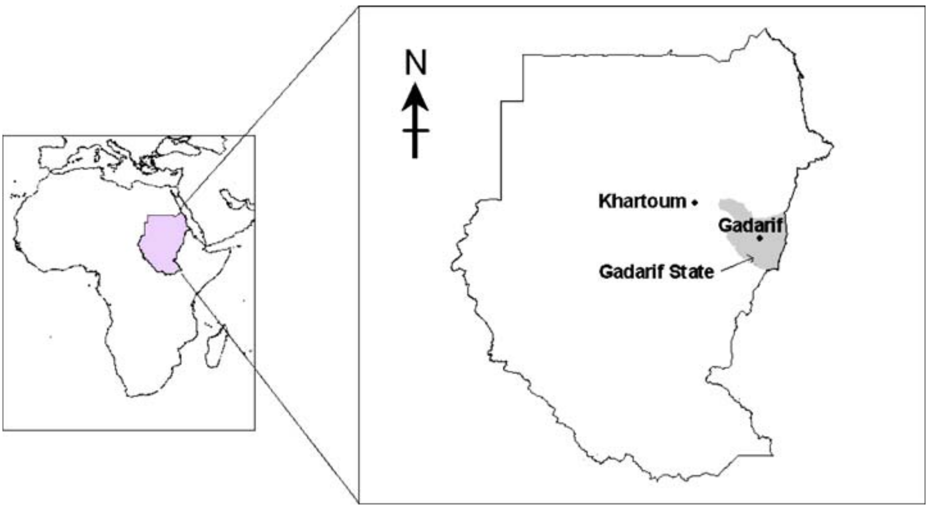

Fig. 1 Location of Gadarif city

strong vitriolic properties. They are nearly impermeable, preventing percolation of seasonal rainwater. As a result, shallow aquifers in most parts of the state are poor or nonexistent (Graham 1969). Beneath the area of Gadarif city the bedrock consists of a basalt ridge overlying Nubian sandstone. As already mentioned, an impermeable clay soil blankets most of the basalt rock in the area. In these particular areas, however, there are places where the basalt is exposed, allowing rainwater to permeate the rock through fissures and cracks. It is for this reason that Graham (1969:412) mentioned that deep well-water can be obtained only from the pediment zone around rocky outcrops, where percolation takes place through the numerous fissures and cracks which penetrate the weathered basalt and sandstone.

2.2 Data

Data for this paper was collected through interviews with city water authorities and the Deputy Director of The Public Organization of the Gadarif Water Supply in August 2006 and October 2008. Published and unpublished government materials regarding water supply and crop production supplemented this study.

3 Discussion and Results

3.1 History of Water Supply in Gadarif

As mentioned above, poor aquifers are a dominant feature in most parts of Gadarif state because the basement complex geological formation is overlain by impermeable clay soils (Mirghani 2002). To adapt to this situation, the people of the region have a long history of rainwater harvesting techniques to provide them and their animals with water. In rural areas, people depend largely on run-off collected in artificial ponds locally called *Hafirs* (Graham 1969).

Gadarif city is no exception. People of the city have suffered an acute shortage of water for decades. Until the end of the 1960s, Gadarif city depended on hand-dug well water from weathered basalt and the Nubian sandstone formation. Pumps with diesel engines are used to draw water from hand-dug wells. These hand-dug wells also represent the main source of water supply for the villagers around the city. Expansions of mechanized farming in Gadarif state have attracted many migrants from within and outside Sudan. This has rapidly increased the population of the city, which in turn has increased the demand for fresh water (Table 1).

During the early 1970s, this region experienced a severe drought. Groundwater recharge decreased, the water table fell, and water became saltier. By the mid 1970s, the authorities began to bring additional water through a pipe from Al-Showak water station, which is located 50 km away from Gadarif at the bank of one of the tributaries of Atbara River. A dam was built on a seasonal tributary of Atbara River and water is pumped from the lake behind the dam directly to main tank in Gadarif city. From there water is distributed through pipes to the different neighborhoods of the city. The amount of water pumped from Al-Showak to the city is 11,000 m^3/day.

Six boreholes were drilled in the late 1960s in Abu Al-Naja area 10 km west of the Gadarif to supply the city with an additional source of water. In the 1980s, because of the high demand for water, 12 new boreholes were drilled in the same area. Since the area is known for its rich aquifers, another 15 boreholes were drilled in 1991 at Al-Azaza village, 8 km north of Abu Al-Naja (Mirghani 2002). The depth of ground water at Abu Al-Naja and around the city ranges between 20 to 82 m. Water is pumped from these boreholes to Abu Al-Naja and Al-Azaza tanks that connected with the city distribution network. Water of Abu Al-Naja and Al-Azaza contributed to the city water supply 1,000–3,000 m^3 and 2,000–2,500 m^3/day respectively. According to the data provided by the water authorities and others, there is fluctuation of the water supply to the city throughout the year. Such fluctuation is largely caused by frequent mechanical and electric power failure (Osman A (2007) Head of the department of the Gadarif external water stations. Personal communication, Gadarif, November 9).

In an effort to protect the city from flood hazards such as those of 1973 and 1993, a small dam was constructed in 1995 on Abu Faragha seasonal stream (*Khor Abu Faragha*), called Al-Saraf Dam (*Sadd Al-Saraf*) (Fig. 2). It is an earth dam built of compacted clay soil, 700 m long, 6 m wide and 6 m high, with a reservoir 476 m wide. The compacted clay of the dam is covered with a 1-m impervious layer. The upstream slope is protected against destructive water action by a layer of broken rock on top of the impervious layer. Native grasses protect the downstream slope from erosion. The dam has a spillway located seven meters from the side of the dam to allow excess floodwater to move downstream. The reservoir's capacity is approximately 2,000,000 m^3. Besides protecting the city from seasonal floods, the water stored behind the dam has infiltrated the soil, increased groundwater supply, and consequently raised the water table. This groundwater, in turn, is available for farming, drinking and other domestic use.

The first indication of the availability of groundwater came from small farmers who earlier had deserted their farms because their wells ran out of water, but now they noticed that the wells were once again supplied. The authorities decided to use

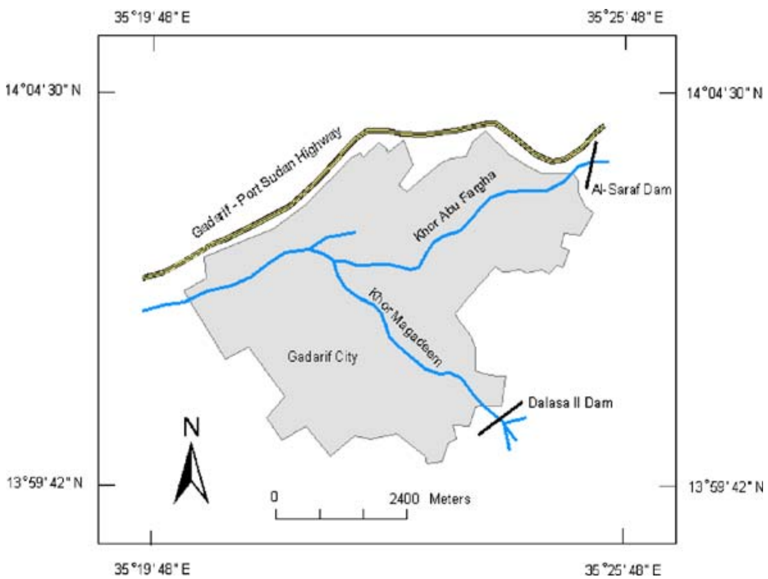

Fig. 2 Location of Al-Saraf and Dalasa II Dams

this "new" groundwater source for the city. By 2003, the authorities had dug ten wells, six deep boreholes to 40 m and four shallow to 15 m in the downstream side of the *Sadd Al-Saraf*. Water from these wells is pumped to the main tank of the distribution network (Public Organization of the Gadarif Water Supply 2005). Such water contributes an average of 700 m^3/day to the city.

The success of Al-Saraf experience encouraged the authorities to build another small dam, Dalasa II in 1998 on the seasonal stream of Magadeem (*Khor Magadeem*) (Fig. 2). Dalasa II is also an earth dam built of compacted clay soil, 400 m long, 6 m wide and 6 m high, with a reservoir 330 m wide. The compacted clay core is of the same length as the dam with an impervious layer, a protective layer of broken rock and a flood spillway. The downstream slope is protected from erosion by a cover of local grasses. The dam is built to store 792,000 m^3 of surface water (Table 2).

It should be noted that both dams were built in narrow valleys of Gadarif Ridge between weathered basalt outcrops. Abu Faragha and Magadeem are seasonal streams that join a larger but unnamed seasonal stream, a tributary of Al-Rahad, which is, in turn, a main tributary of the Blue Nile. Al-Rahad stream runs during the rainy season, becoming an intermittent stream during the dry season.

Beside many hand-dug wells for irrigation that already exist on small farms along Magadeem stream, the authorities have dug seven new deep boreholes and four new shallow wells at the downstream side of Dalasa II, to supply the city with water. Until the year 2006, the results of Dalasa II were similar to that of Al-Saraf; the rising water tables contributed an average of 700 m^3 per day to the city water system. In 2007, because of the desiltation of the reservoir, groundwater recharge has increased and Dalasa II contributes an average of 1,500 m^3/day to the city water supply (Table 3). In addition, it supplies the nearby villages with water carried by water vendors.

Groundwater levels fluctuate from 5 m below the surface during the rainy season to 8 m below the surface during the dry season. During the dry season, where no recharge is possible due to constraints of climate, the production of the wells in both dams continues at 2,200 m^3/day. No drawdown effect has been observed other than a seasonal lowering of groundwater by 3 m. However, by April, although recharge has largely restored groundwater, the surface water of the reservoir has run completely dry. This tends to support the belief that the daily 2,200 m^3 of water production is at least sustainable and possibly could be increased within the recharge capacity of the aquifer. The precise infiltration rates of the dams have never been measured directly, however, it has been observed to fill to near capacity at many times throughout the rainy season.

A total of seven neighborhoods of the city and several villages are provided with water pumped from the groundwater recharged by the two new dams on a daily basis.

Table 3 Average contribution of different sources of Gadarif water supply in cubic meters per day

Source	Average contribution
Al-Showak	11,000
Abu Al-Naja	2,000
Al-Azaza	2,250
Al-Saraf	700
Dalasa II	1,500
Other sources	1,400
Total	18,850

Source: Field Survey 2006 and 2008

Four city neighborhoods enjoy the groundwater of Al-Saraf (Karari, Dar Al-Salam, Al-Engaz and Al-Thawara) as well as the villages of Al-Ogal, Wad Al-Said, Um Shigara, Wad Amir and others. Water from Dalasa II is extended to Daim Al-Nur, Suakin, Al-Malik and Marko neighborhoods, while the villages of Abbayo, Dalasa Al-Arakieen, Al-Amara, Dalasa Shorab, Hillat Omer and Al-Sharief Al-Agib get their drinking water from boreholes near Dalasa II.

The water is treated and purified with chlorine in the main tank before distribution to users. Meanwhile, other parts of the city receive water from the other sources every other day.

In addition to these local effects, the cracks and fissures in the basalt and sandstone of the Gadarif area have enhanced both the vertical recharge of water from the reservoirs of these dams and the spatial extension of deep groundwater. Vertically, water tables have increased several meters and spatially the aquifers have extended for about 20 km downstream. The renewed availability of groundwater in this wide area not only recharged abandon dry wells but also has encouraged city authorities and villagers to drill more boreholes and wells for drinking and farming.

In the last five years, following the success of Al-Saraf and Dalasa II, two further dams were added, the Ed Al-Teen and Al-Sharief Al-Agib that were built by both local authorities and a local NGO called Public Organization of Gadarif Water Supply. At present both of the new dams facilitate water infiltration to the local aquifer, however water supply wells have not yet been established at either location. For now, both new dams only function to augment recharge of groundwater (Table 2).

3.2 Problems of Water Supply

Water of the upstream dams has helped, but they have not completely solved the city water problem. For one thing, the main source of water of Al-Showak is Atbara River, but that river has many problems. In the rainy season, high floods adversely affect the station. Then towards the end of the dry season (April–May), the river becomes intermittent pools away from the station. In both cases, the total quantity of water is short of the city requirement. The dry season pools contain stagnant water that is used by people and animals alike, hence water quality, smell and taste deteriorate. In addition, Al-Showak water passes through land occupied by nomadic groups. In the dry period, when water shortages become acute, pastoralists break the pipeline to water their animals.

On the other hand, with the daily heavy pumping, ten of the new Abu Al-Naja boreholes have dried out. Frequent electric and mechanical failure at Abu Al-Naja area cause additional stress in the daily water supply.

In short, the recharged groundwater by the newly built small dams has posed problems as well as opportunities. At first, the main problem was the high concentration of salt in the water. With time and heavy discharge, salt has been reduced to the extent that people can drink fresh safe water. Now, salt is experienced only towards the end of the dry season, when infiltration of water from the reservoirs is stopped. The story of nitrate contamination follows a similar arc. At first, misuse of the dam surface water by human and animals caused the percentage of nitrate in the groundwater to increase. The reason behind this is that a fence or a guard does not protect the Dalasa II dam. On the other hand, despite the fact that Al-Saraf is fenced, during the

Fig. 3 The upstream of Al-Saraf Dam Flora and Fauna have changed

fieldwork it was found broken and hence people and animals enter into the dam and reservoir area. After 10 years, however, that problem has been eliminated.

To date, all of these sources provide the city with only half of its daily requirement of water. Occasional technical problems cause even further shortage of water. One of the solutions suggested by the city authorities is to move Al-Showak station to a new location where water will be available during the dry season.

3.3 Ecological Changes

Following the building of the two dams, some ecological changes took place in the area. These include changes in the flora and fauna of Al-Saraf reservoir and siltation of the Dalasa II reservoir. Similar to many man-made reservoirs in many parts of the world, Al-Saraf dam has affected the flora and fauna of the area (Avakyan and Podol'skii 2002; Topuzovic and Pavlovic 2004). Availability of water enhances the growth of trees in the reservoir area, which then becomes a refuge to local and migratory birds in an agricultural region where most trees were cleared a long time ago (Mustafa 2006:37). The trees that grow in the reservoir have become a recreation area for the city population in the dry season (Fig. 3). It has been noticed that throughout these years Al-Saraf dam has not been affected by siltation. In contrast, Dalasa II dam is almost bare of trees and has been affected by siltation. To treat the problem of siltation, authorities have removed the silt, built a check-dam upstream, and planted trees in the catchment area upstream. Desiltation of the reservoir in 2007 has increased the recharge and as a consequence, Dalasa II's contribution to the city water supply has increased by more than 100%.

4 Conclusions

This paper has documented the experience of people who have tried many different strategies to solve the problem of urban water supply in a seasonal climate. Some small dams around the Gadarif city provide multiple benefits. They were originally built for flood control, but now they also provide a groundwater resource of 2200 m^3/day, which is approximately 12% of the total supply of the city, plus a daily allocation of water for vegetable growing.

The success of these small dams has encouraged the authorities to expand this strategy as part of a long-term solution for the water supply in the city. Given that the city water total supply is only 53 l/capita/day, this source could supply roughly 42,000 people with good quality water.

The greater adequacy of water supply is also expected to have a positive influence on the socio-economic life of people in small villages around the city. Before the dams, vegetables had to be brought from far distances during the dry season and they were sold in the city at very high prices. Now that groundwater is becoming available all year long, farmers are able to cultivate some vegetables throughout the year and supply the city markets with vegetables at affordable prices. In this way, the dams have increased the income and thus enhance the well being of small farmers.

On a regional basis, year-round aquifers will encourage more agricultural investors to settle in the city. Previously, most owners of mechanized farms in the Gadarif state lived in other larger cites and entrusted their farms to hired labors (*Wakeel*) (Mustafa 2006; Woodward 1990). Agricultural production, in turn, suffered from the absence of farm owners. Settling of these owners is expected to increase agricultural productivity. In short, the availability of water supply will enhance food security, reduce poverty in rural areas, provide water for the city, and even promote the greening of the city with trees that can help environmental conservation and recreation. Finally, given the factors of climate change and increasing urban population, rainwater harvesting can be a reasonable solution for water shortage. Co-operation between official efforts and local NGOs (public participation) yields better results in water supply management (Balooni et al. 2008; Handia et al. 2003).

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References

Abdelkhaleq RA, Ahmed IA (2007) Rainwater harvesting in ancient civilizations in Jordan. Water Sci Technol 7:85–93. doi:10.2166/ws.2007.010

Al-Muttair FF, Al-Turbak AS (1991) Modeling of infiltration from an artificial recharge basin with a decreasing ponded depth. J King Saud Univi 3(1):89–100

Al-Muttair FF, Sendil U, Al-Turbak AS (1994) Management of recharge dams in Saudi Arabia. J Water Resour Plan Manage 120(6):749–763. doi:10.1061/(ASCE)0733-9496(1994)120:6(749)

Al-Rashed MF, Sherif MM (2000) Water resources in the GCC countries: an overview. Water Resour Manage 14:59–75. doi:10.1023/A:1008127027743

Al-Turbak AS (1991) Effectiveness of recharge from a surface reservoir to an underlying unconfined aquifer. In: Proceedings of the Vienna symposium of the hydrology of natural and manmade lakes, pp 191–196

Avakyan AB, Podol'skii SA (2002) Impact of reservoirs on the fauna. Water Resour 29(2):123–132. doi:10.1023/A:1014940901903

Balooni K, Kalro AH, Kamalamma AG (2008) Community initiatives in building and managing temporary check-dams across seasonal streams for water harvesting in south India. Agric Water Manage 95:1314–1322. doi:10.1016/j.agwat.2008.06.012

City Population (2007) Sudan overview. http://www.citypopulation.de/Sudan.html. Last accessed 15 November 2007
de Vries B (1997) Umm el-Jimal. The Oxford encyclopedia of archaeology in the Near East. Oxford University Press, London, pp 276-279
Gould J, Nissen-Petersen E (1999) Rainwater catchment systems for domestic supply: design, construction and implementation. Intermediate Technology, London
Graham A (1969) Man-water relation in the east central Sudan. In: Thomas M, Whittington G (eds) Environment and land use in Africa. Methuen, London, pp 409-445
Handia L, Tembo JM, Mwiindwa C (2003) Potential of water harvesting in urban Zambia. Phys Chem Earth 28:893–896
Kumar MD (2004) Roof water harvesting for domestic water security: who gains and who loses? Water Int 39(1):43–53
Mirghani M (2002) Concepts and models for the characterization of the west Gedaref Hydrogeologic system, Sudan. PhD Dissertation, Technical University of Berlin
Murad AA, Al Nuaimi H, Al Hammadi M (2007) Comprehensive assessment of water resources in the United Arab Emirates (UEA). Water Resour Manage 21:1449–146. doi:10.1007/s11269-006-9093-4
Mustafa RH (2006) Risk management in the rain-fed sector of Sudan: case study, Gedaref area eastern Sudan, PhD thesis, Justus-Liebig University, Giessen, Germany
Oleson JP (1995) The origins and design of Nabataean water supply system. Studies in the history and archaeology of Jordan, vol V. Department of Antiquities, Amman, Jordan
O'Hara JK, Georgakakos KP (2008) Quantify the urban water supply impacts of climate change. Water Resour Manage 22:1477–1497. doi:10.1007/s11269-008-9238-8
Pandey DN, Gupta AK, Anderson DM (2003) Rainwater harvesting as an adaptation to climate change. Curr Sci 85(1):46–59
Postel SL, Daily GC, Ehrlich PR (1996) Human appropriation of renewable fresh water. Science 271:785–788. doi:10.1126/science.271.5250.785
Preul HC (1994) Rainfall-runoff water harvesting prospects for greater Amman and Jordan. Water Int 19(2):82–85
Public Organization of the Gadarif Water Supply (2005). http://www.gedaref.com/publicorg/index.htm. Last accessed 20 February 2007
Raju NJ, Reddy TVK, Munirathnam P (2006) Subsurface dams to harvest rainwater- a case study of the Swarnamukhi River basin, Southern India. Hydrogeol J 14:526–531. doi:10.1007/s10040-005-0438-5
Ruth M, Bernier C, Jollands N, Golubiewski N (2007) Adaptation of urban water supply infrastructure to impacts from climate and socioeconomic changes: the case of Hamilton, New Zealand. Water Resour Manage 21:1031–1045. doi:10.1007/s11269-006-9071-x
Sendil U, Al-Turbak AS, Al-Muttair FF (1990) Management plans for artificial reservoir recharge. Int J Water Resour Dev 6(3):163–169. doi:10.1080/07900629008722468
Thomas T (1998) Domestic water supply using rainwater harvesting. Build Res Inform 26(2):94–101. doi:10.1080/096132198370010
Topuzovic M, Pavlovic D (2004) Physical organization of two reservoirs in Serbia as a crucial factor in development of their hydrophilic flora: a comparative study. Hydrobiologia 525:239–243. doi:10.1023/B:HYDR.0000038863.71196.42
Wheida E, Verhoeven R (2007) An alternative solution of the water shortage problem in Libya. Water Resour Manage 21:961–982. doi:10.1007/s11269-006-9067-6
Woodward P (1990) Sudan 1898–1989: the unstable state. Lynne Rienner, Boulder
World Gazetteer (2007) Sudan: largest cities and towns and statistics of their population. http://www.world-gazetteer.com/wg. Last accessed 6 November 2007