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Review

Sand water storage: Unconventional methods to freshwater augmentation in isolated rural communities of South Africa

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South Africa water resources are scarce in global terms with mean annual rainfall of about half world average of 860 mm a year. On the other hand, current economy development with resulting contamination of available water resources will further reduce water availability, if present patterns of water use continue unchanged. The conventional water resources (largely surface water) in the country have been fully exploited with little opportunity for further expansion. So therefore, new approaches are necessary by accessing alluvial aquifers of non-perennial rivers in forming additional water resources in this part of semi-arid region. High evaporative losses from surface storage, increasing costs of large dams and aridity conditions have hindered development of conventional water resources with increasing interest in using groundwater for rural water supply. Many South Africa rivers are non-perennial, therefore, development of unconventional sand water storage is appealing for freshwater augmentation in isolated rural communities. This paper presents overviews of South Africa water resources highlighting sand water storage options for potential application in rural water supply for isolated communities where groundwater potential is low.

Key words: Rural water supply, groundwater dam, runoff harvesting, non-perennial river.

INTRODUCTION

South Africa is semi-arid and is classified as a water-stressed country (Tewari, 2005). Freshwater is limited and in great demand as population increases. As a result, demand for water far exceeds the capacity of several catchments to provide. Over 50% of South Africa's catchments are considered to be over-allocated (Pott et al., 2009) as surface water resources become fully developed. In the context of rural development, rural communities use water for a wide range of productive and domestic uses, all of which are important to their livelihoods. However, the water from streams, rivers and reservoirs is no longer enough to assure increasing water demand in many rural areas under semi-arid conditions.

As migration from rural to urban areas increases, access to a sustainable and adequate supply of water is critical in rural semi-arid areas.

Therefore, the need to increase water resources in meeting growing water demand has been recognised more than ever. The isolated rural communities often depend on groundwater for all their water requirements and overexploitation of groundwater is usually experienced. In many high demand areas, rate of extraction of groundwater has exceeded the rate of natural recharge, causing continuous decline in ground-water levels and depletion of aquifers. Smakhtin et al. (2001) considered contributing factors to slow rates of groundwater recharge as low rainfall combined with high rates of evaporation experienced in semi-arid regions. As climate change leads to more extreme variations, there have been expressed concerns about the adequacy and availability of water resources world-wide. Rural

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Table 1. Rural water coverage in South Africa.

Level of service	Description	Percentage coverage
Minimal	No infrastructure	40
Upgradable	Upgrading required in order to be classified as basic	25
Basic	25l/c/d to within 200m of every resident	20
Intermediate	Households have access to yard taps	10
High	Households have access to in-house connection	5

Source: Webster (1999).

settlements with limited availability of surface water in drought prone region, such as South Africa, will be more vulnerable to the effect of water shortage. In response to extreme water scarcity, more emphasis on groundwater replenishment is needed. Groundwater is the only permanent source of water in arid and semiarid regions and development offers possible optional methods for developing water resources (Onder and Yilmaz, 2005) to ease future water scarcity.

Despite an increase in other several options for water resources development, sustainability, cost and associated environmental impact are some of the factors hindering their implementations. In urban areas, dam construction, long-distance conveyance of water or desalinisation may provide alternatives for ensuring water availability. However, such solutions are too costly and complicated for rural water security. Rural populations need low-cost systems that can be constructed, operated and maintained with a high degree of community involvement and autonomy. Sand water storage is low technology and artificial improvement of traditional practice that put extra water into sand-beds of intermittent rivers, to recharge and store for use during prolonged dry periods. The development will provide traditionally acceptable methods in rural communities under arid conditions with no environmental problems. These methods, coupled with modern hydrological tools may supplement classical means of water resources development and help to secure future rural water supply. In the past, traditional methods have played a much greater role and were backbone of ancient civilizations in arid and semi-arid areas around the world. This paper presents general overview of water resources in South Africa and brings to focus the unconventional methods of runoff storage in sand. The method can be applied with low investment costs and of good prospect in alleviating water scarcity in rural isolated communities of South Africa.

Overview of water resources and rural water outlook

South Africa climate varies from semi-desert in the western part to sub humid along the eastern coast (DWAF, 2004). Western parts of the country are both arid and hot. Large areas are regularly subjected to series of prolonged dry periods that are often broken by intense rainfall. South Africa has limited amount of rainfall a year with clear division between dry and rainy periods. Rainy period is often followed by a long dry period. The average annual rainfall is approximately 460 mm slightly less than half of the world average. The rainfall is irregular in both time and space. The total annual surface runoff of all rivers averages around 49 000 million m^3 less than half of the Zambezi's annual flow (DWAF, 2004).

However, about 75% of runoff flows into the sea along the Eastern and Southern seaboards. The annual potential evapotranspiration is greater than the annual rainfall. A combination of high variable rainfall and runoff within the rain season and higher evaporation reduces river flow to low levels for most of the time and some are even without water during prolonged dry period. Sometimes unpredictable high flow is experienced resulting in soil erosion and large flash floods carrying large amounts of sediment loads (Keay-Bright and Bordman, 2009). Natural availability of water across the country is unevenly distributed (Tewari and Kushwaha, 2008). Compared with other neighbouring countries, South Africa water resources are small, while groundwater often represents the most important and alternative source of water for towns and villages (Mukheibir and Sparks, 2006). Isolated rural communities at the heart of resources insecurity are more vulnerable to temporal and spatial variability. Major rural communities' economies are agricultural based and sustained by irrigation. Contamination of available water resources by agro-chemical may further decrease water availability with growing difficulties of meeting basic human needs.

Accessibility to water is a major concern to water managers and South Africa rural areas which represent 45% of the total population are the most vulnerable (CSS, 1997). Webster (1999) depicts rural water coverage in South Africa as shown in Table 1, with figures suggesting that 35% of all rural dwellers have access to an "adequate" water supply and 65% does not have access. Limpopo province (North West Province) is one of the driest and poorest provinces in South Africa (Machethe et al., 2004). 90% of its population resides in villages and is exposed to high health risk due to infection and other diseases (DBSA, 2000). According to North West Province Environmental Outlook (2008) rural water users currently need about 70 million m^3 a year, of which 25

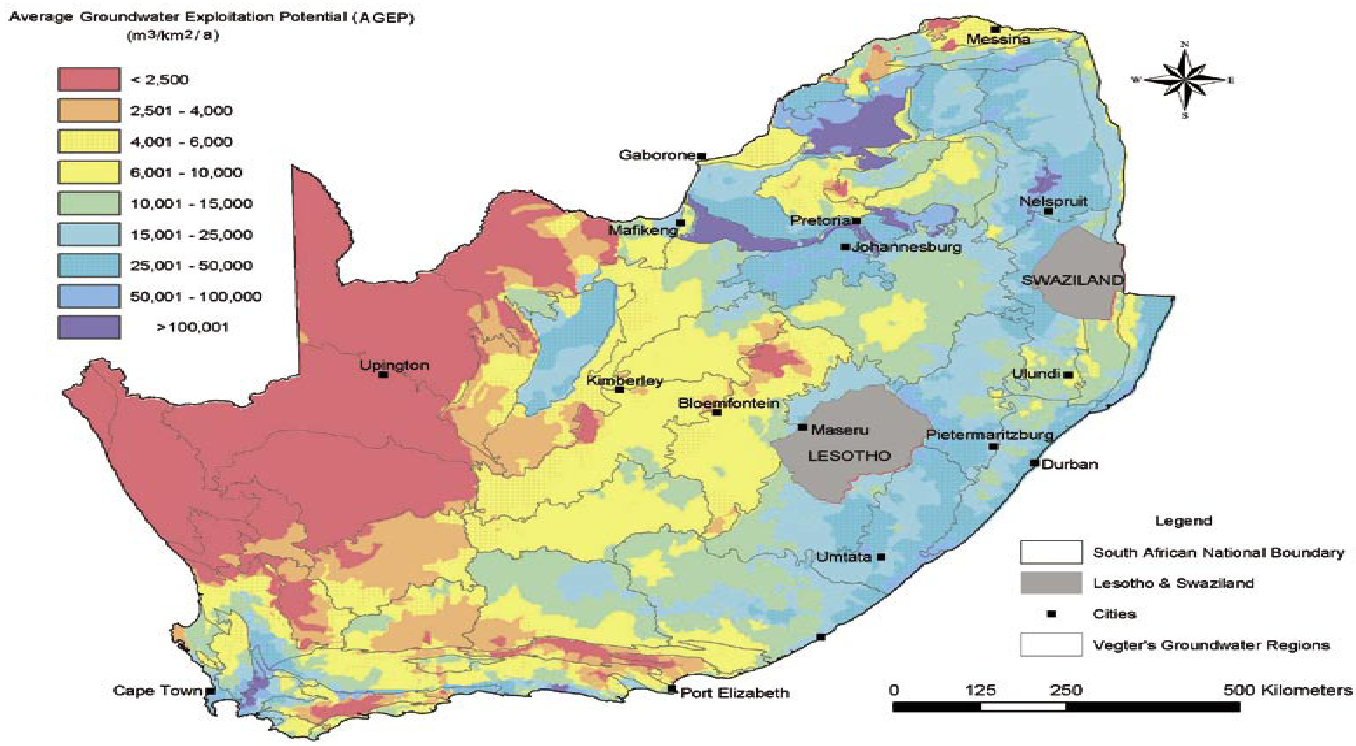

Figure 1. Average groundwater exploitation for South Africa.

Table 2. South Africa groundwater use by sectors.

Water use sector	Total water (Mm^3/year)	Percentage total
Urban use	70	3.9
Rural domestic	120	6.7
Stock-watering	100	5.6
Irrigation	1400	78.2
Mining and quarries	100	5.6
Total	1790	100

Source: Tewari and Kushwaha (2008).

million m^3 a year is used for domestic consumption and the rest used for stock-water and subsistence agriculture. Groundwater is hence a strategic resource in Limpopo.

Groundwater resources

Alluvial pools are a widespread occurrence under semi-arid conditions. Most of South Africa's rivers are ephemeral (Braune and Xu, 2010) with temporary surface flow that varies between seasons. The rivers flow for short periods following heavy rainfall and there are no navigable rivers (DWAF, 2004). Aquifer storage to hold part of the natural flow in seasonal rivers is essential with more than 60% of the river flow arising from only 20% of the land (Tewari and Kushwaha, 2008). The basic principle of aquifer storage is that, instead of storing water at the surface, water is stored in the subsurface. Sand can store substantial quantities of water in the voids between the particles if they are not filled by smaller particles. A coarse sand of uniform size could store up to 45% of its volume as water within the sand (Hudson, 1987). One of the advantages of subsurface storage is the loss of water due to evaporation, which is negligible than that of surface reservoirs. Groundwater contributes a few of the total available water in rural areas of South Africa.

According to Braune and Xu (2010), and Tewari and Kushwaha (2008), 60 to 90% of rural areas depend on groundwater. Figure 1 shows groundwater exploitation in South Africa while Table 2 gives the breakdown of groundwater use. As a result, the groundwater resources

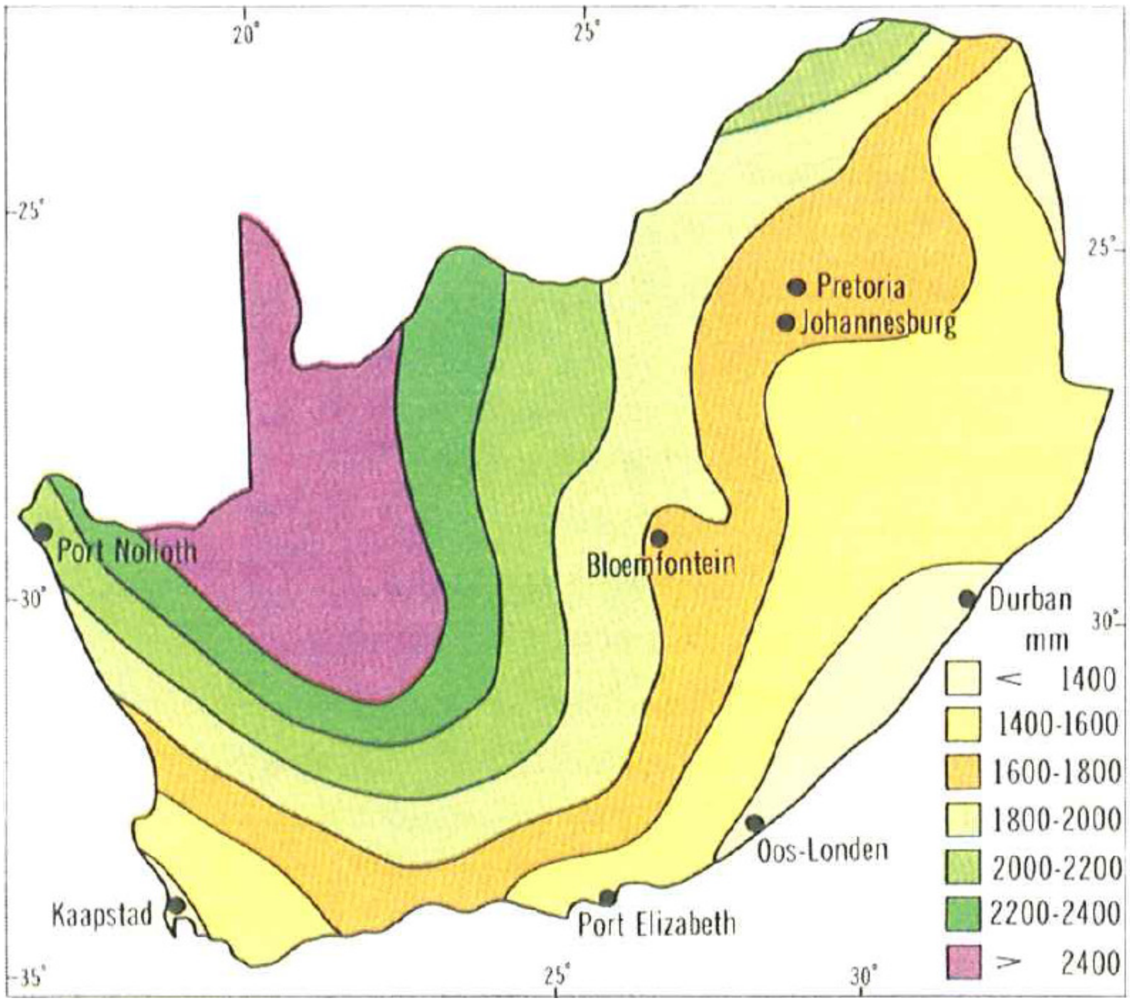

Figure 2. Simplified map of evaporation rates across South Africa (mm/annum).

have assumed great importance as the principal source of freshwater in this semi-arid area (Braune and Xu, 2010). Aridity conditions are considered to influence development of subsurface water. Since dams for surface storage are increasingly difficult to build because of site limitations and unfavourable environmental, technical, and sustainability. Also, evaporation losses cause surface dams to be inefficient for long-term storage, since it has to cope with changes in climate. Van Dijk and Van Vuuren (2008), depict evaporation bands across South Africa with simplified map of evaporation rates shown in Figure 2.

As shown in Figure 2, the evaporation rate is greater than 1400 mm per annum for most of the country. Evaporation has a significant influence on the yield of water supply reservoirs and on the economics of building reservoirs of various sizes (Van Dijk and Van Vuuren, 2008). Presently, over 2,000 mm^3 is lost each year through evaporation from surface storage reservoirs. This is estimated to about 7.5% of total capacity in the country and nearly equal to the volume of water stored in the largest dams in South Africa (Smakhtin et al., 2001). While remote communities rely mostly on groundwater, there are strong signs of receding groundwater levels from recent studies over years (Hugo and Hattingh, 1971). Therefore, to ensure best stability in the use of groundwater, it is essential to undertake measures to increase groundwater recharge. Aquifer storage provides a potential means for fulfilling such measures.

Runoff water harvesting and artificial recharge to groundwater

The problem of water shortage in arid and semi-arid areas is not only because of uneven distribution and low rainfall throughout the season, but also untapped potential of excess runoff for use when needed. Harvesting of runoff water is a principle of collecting and using runoff from a catchment surface. Runoff catchment technologies have only been used on a rudimentary level in South Africa. However, no significant impact in solving

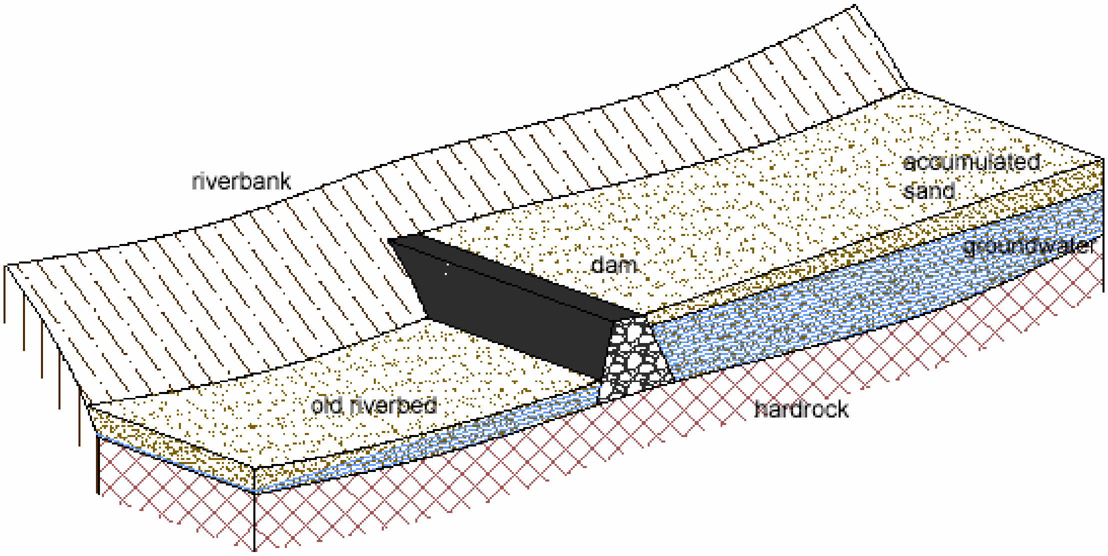

Figure 3. Schematic representation of a sand-storage dam. Source: Quilis et al. (2009).

rural or urban water supplies problems have been made. Recharge to groundwater is not a new idea of runoff harvesting but rather a new term employed to describe unconventional traditional means of subsurface storage.

The storage techniques used in runoff harvesting can be classified as above-ground storage and artificial recharge to ground. The artificial recharge to groundwater aims at increase of groundwater reservoir, by adapting the natural movement of surface water using suitable civil construction techniques. Onder and Yilmaz (2005) described runoff harvesting by sand water storage as in-stream adjustment of stream bed barricaded with weir of suitable size. Sand carried by heavy flows during the rains is deposited upstream of the weir and the reservoir is filled up overtime with sand. This forms an artificial aquifer which is replenished each year during rain. The water stored in the sediment below the ground surface can be used to recharge an aquifer or to raise groundwater levels of an aquifer, thus making it accessible for abstraction. Sand water reservoir system is illustrated as shown in Figure 3.

Aquifer storage

Sand water storages are indigenous methods where surface runoff is stored in the ground by infiltration. Their main function is to store water for short or long-term periods in sand voids of sediment deposition from alluvial channel in ephemeral rivers. Other objectives or side benefits include decrease of downstream erosion and protection from evaporation losses and subsequent quality improvement of the water during abstraction, as it flows through various zones and aquifers.

This soil-aquifer treatment or geopurification plays an important role in water reuse, especially where water purification cost is prohibitive in rural areas. Sand water storages are sustainable because with single flash floods, reservoir can be brought to its full capacities. However, their design and functionality are based on the topography of the catchment areas. Wills (2008) suggests an idea of subsurface water storage for South Africa as water conservation and storage for municipalities in response to the growing water scarcity.

SUMMARY AND CONCLUSIONS

One of the 7 agenda of the Millennium Development Goals (MDGs), as noted by Mwenge et al. (2007) is decreased by half the proportion of people without sustainable access to basic water. South Africa is a mixture of developed and developing regions, and about 9.7 million (20%) of the people do not have access to adequate water supply. Harvesting runoff with specific reference to Sand water storage was selected because runoff harvesting technology is not prevalent in South Africa despite its potential for augmenting freshwater in the country. The application is mainly concentrated on roof catchment in the rural areas. However, potential application of runoff harvesting technology is high, especially in the rural catchments falling within the deficit Water Management Area (WMA) such as Limpopo province. Runoff harvesting has the potential in this region to supply water to rural and even to peri-urban areas that conventional technologies cannot supply.

One of the basic conditions justifying construction of sand water storage for runoff harvesting technique in rural areas is depleting groundwater through groundwater base flow and over abstraction. Run-off storage in sand reservoirs is essential to solve the important growing problem of reduced groundwater levels which causes water scarcity in rural areas. Many a time, deep groundwater exploration, development and abstraction are expensive and beyond the reach of rural dwellers and thus preventing access to safe water. It is recommendable to establish and decentralise sand water storage reservoir in rural areas where the potential exists and serves as model for other similar areas. This will be probable options for a large part of the new water demand thus make it strategically important alternatives.

Sand water storages described are possible means of increasing groundwater availability in the respective demand sectors and thus hold potential for research into their further understanding. South Africa rural areas have a good share of sandy seasonal rivers that are prone to siltation; an ideal condition for sand water storage application. However, previous evaluation of alternative technologies for freshwater augmentation in Africa shows that despite the high effectiveness of sand water storage in augmenting freshwater in Africa, its extent of use has been limited to Kenya, Zimbabwe, Egypt, Libya, Tunisia and Algeria (UNEP, 2003) Therefore, there is need to promote the technology more in South Africa. Although, improving water productivity by ensuring that water resources are reliable will need the right mix of manageable technologies and appropriate incentives. By linking groundwater sources to a water supply system that obtain from subsurface storages on ephemeral rivers, a major contribution can be made to increase alternative strategies available for water supply management in isolated rural communities.

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REFERENCES

Braune E, Xu Y (2010). The role of ground water in sub-Saharan Africa. Ground Water, 48(2): 229-238.

CSS (1997). Census '96 preliminary estimates of the size of the population of South Africa, Pretoria, SA.

DWAF (2004). National Water Resources Strategy. RSA

DBSA (2000). Development report: building local government, development of South Africa. Johannesburg: Halfway House.

Hudson NW (1987). Soil and water conservation in semi-arid areas, Soil Resources, Management and Conservation Service, FAO Rome. 57: 109-122.

Hugo ML, Hattingh PS (1971). An analysis of bed material in ephemeral streams of South Africa, Zeitschrift für Geomorphologie, 12: 191-196.

Keay-Bright J, Bordman J (2009) Evidence from field-based studies of rates of soil erosion on degraded land in the central Karoo, South Africa. Geomorphol., 103(3): 455-465.

Machethe CL, Mollel NM, Ayisi K, Mashatola MB, Anim FDK, Vanasch F (2004). Smallholder irrigation and agricultural development in the Olifants River Basin of Limpopo Province: management transfer, productivity, profitability and food security issues, Water Res. Commission, 1050: 1-4.

Mukheibir P, Sparks D (2006). Climate variability, climate change and water resources strategies for small municipalities. Pretoria: Water Research Commission Report, 1500: 1-6.

Mwenge K, Taigbenu AE, Boroto JR (2007). Domestic rainwater harvesting to improve water supply in rural South Africa. J. Phys. Chem. Earth., 32: 1050-1057.

North West Province Environmental Outlook (2008). A report on the state of the environment. [Online]. Available: http:\\www.nwpg.gov.za/Agriculture/NW-ENVIRONMENTAL_OUTLOOK

Onder H, Yilmaz M (2005). Underground dams. European Water. 11(12): 35-45.

Quilis RO, Hoogmoed M, Ertsen M, Foppen JW, Hut R, de Vries A (2009). Measuring and modeling hydrological processes of sand-storage dams on different spatial scales. J. Phys. Chem. Earth., 34(4): 289-298.

Pott A, Hallowes J, Backeberg G, Döckel M (2009). The challenge of water conservation and water demand management for irrigated agriculture in South Africa. Water International, 34(3): 313-324.

Smakhtin V, Ashton P, Batchelor A, Meyer R, Murray E, Barta B, Bauer N, Naidoo D, Olivier J, Terblanche D (2001). Unconventional water supply options in South Africa: a review of possible solutions water International, Int. Water Resources Assoc., 26(3): 314-334.

Tewari DD (2005). A brief historical analysis of water rights in South Africa. Water Int., 30(4): 438-445.

Tewari DD, Kushwaha RL (2008). Socio-economics of groundwater management in Limpopo, South Africa: poverty reduction potential and resources management challenges. Water Int., 33(1): 69-85.

UNEP (2003). Water-Two billion people are dying for it. Conference materials: Green Week, Changing our behavior, Brussels.

Van Dijk M, Van Vuuren SJ (2008). Reduction of evaporation from reservoirs. The Proceedings of Water Institute of Southern Africa, Biennial Conference and Exhibition, Sun City, Rustenburg. 18-22 May.

Webster MJ (1999). Effective demand for rural water supply in South Africa, WEDC, Loughborough University UK. p. 15.

Wills M (2008). Artificial recharge gets real. The Wheel. Water Research Commission, Pretoria, 7(4): 11-14.