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Review article

Synthesis on groundwater recharge in Southern Africa: A supporting tool for groundwater users

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ABSTRACT

This synthesis on groundwater recharge targets the Southern African region as a result of the dependence of the community and economic sector on the groundwater resource. Several literature based recharge studies were collected and assessed in order to find out the main controls to the occurrence of recharge. The Water Table Fluctuation and Base flow separation methods have been tested in the catchment that drains crystalline basement rocks and dolostones close to the city of Johannesburg, South Africa. Based on the assessed data the Chloride Mass Balance method resulted in groundwater recharge of less than 4% of the rainfall, while it reaches 20%, when rainfall exceeds 600 mm. For the classical water balance method, recharge proportion is less than 3% of rainfall as a result of very high ambient temperature in the region. Based on the Saturated Volume Fluctuation and Water Table Fluctuation methods, recharge could be less than 6% for annual rainfall of less than 600 mm. Observational results further suggest that sporadic recharge from high intensity rainfall has important contribution to the groundwater recharge in the region, owing to the presence of permeable geological cover, which could not be fully captured by most of the recharge estimation methods. This study further documents an evaluation of the most reliable recharge estimation methods in the area such as the chloride mass balance, saturated volume fluctuation and water table fluctuation methods in order to successfully manage the groundwater resource.

1. Introduction

The presence of reliable groundwater recharge from rainwater in certain region is a fundamental factor for the sustainable use of the resource in enhancing economic development. Besides the scientific interest, information on recharge may allow a better understanding of the resource and its optimal management strategy. Understanding the appropriate geological context can also provide criteria for water management in the region. Unlike humid regions, groundwater resource in arid and semi-arid areas such as in the Southern African region, play strategic role in various economic sectors. Hence, groundwater recharge is important factor to sustain the need of the population. Lerner et al. (1990) have conceptually defined recharge mechanisms as direct (direct infiltration of precipitation and subsequent percolation through the unsaturated zone to a groundwater body), indirect (percolation to the water table through riverbeds) and localized recharges (accumulation of precipitation in surface water bodies, and subsequently concentrated infiltration and percolation through the unsaturated zone to a groundwater body). The fact of the matter is that groundwater recharge takes place through a complex network of soil and rock structures in the form of residual rainfall and depends on the physical nature of an aquifer rather than rainfall amount. Aquifers are controlled by the diverse geological setting, degree of fracturing and weathering processes.

The model based groundwater recharge estimation methods in Southern Africa have been discussed in Xu and Beekman (2003), who identified challenges in the application of the recharge estimation methods. According to the study, the most promising methods for recharge estimation are the Chloride Mass Balance (CMB), Cumulative Rainfall Departure (CRD), Extended model for Aquifer Recharge and moisture Transport through unsaturated Hardrock (EARTH), Water Table Fluctuation (WTF), Groundwater Modelling (GM) and Saturated Volume Fluctuation (SVF) methods (Xu and Beekman, 2003). The methods that are based specifically on relationships between rainfall, abstraction and water level fluctuations, such as the CRD and EARTH methods have been used to forecast groundwater recharge from rainfall. Several of the recharge estimation methods have their own drawbacks, which could generate inaccurate values due to errors in parameter estimation and spatial coverage of the processes (Bredenkamp et al., 1995). It is clear that the above mentioned methods estimate recharge with different error margins, however, highly intensive rains associated with cyclonic events are important

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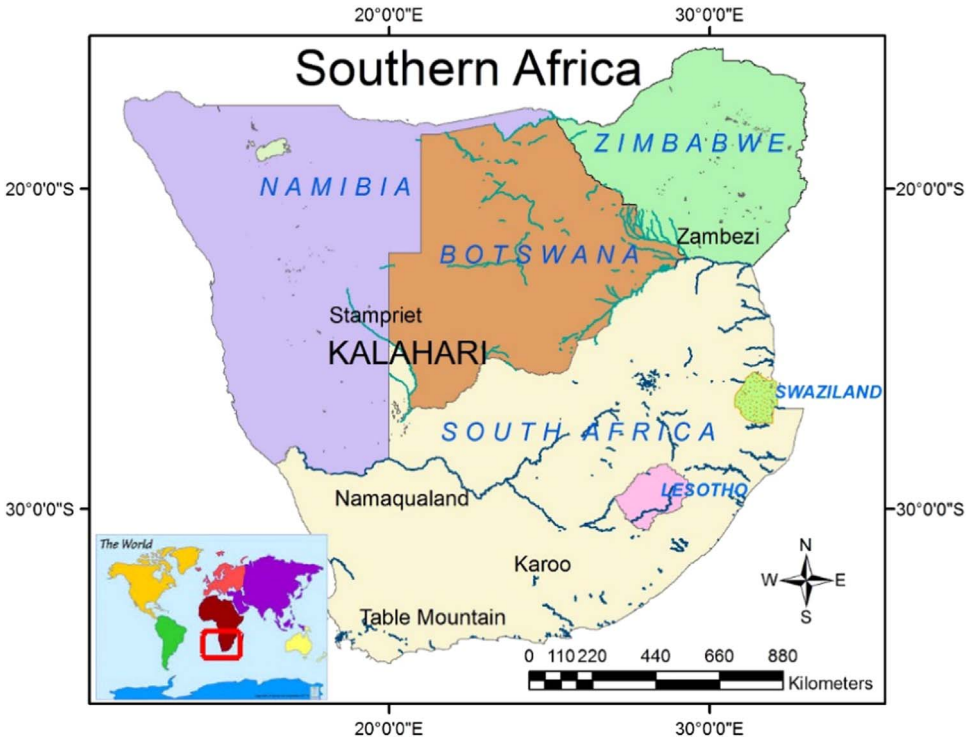

Fig. 1. Map showing countries considered in the study with some landmarks..

in generating substantial recharge in the region. Therefore, it is crucial to provide knowledge-based guidance for policy- and decision-makers in groundwater utilization in order to achieve sustainable social and economic development in the region.

In arid and semi-arid areas of the Southern African region (Fig. 1), which is characterized by sporadic rainfalls particularly in South Africa, Namibia, Botswana, Zimbabwe, Lesotho and Swaziland with total surface area of 3.09 million km^2 and population of 74.8 million, the occurrence of effective recharge to groundwater could be underestimated, which mostly happens only after extraordinarily high rainfall event. Episodic recharge, sometimes referred as irregular pulses of groundwater recharge, was investigated in detail in South Africa by Bean et al. (2004), Van Wyk (2010) and Van Wyk et al. (2011). It has been understood that this type of recharge process is important for the region, but difficult to quantify due to the unpredictability of the rainfall event.

Groundwater recharge estimation in arid and semi-arid areas needs to be approached with caution in order to optimally manage the resource. Owing to the lack of dependable surface water due to climatic aridity and expanding drought (Fig. 2), groundwater, which is stored over a ca. millennia, provides life-saving water for the local community. Groundwater is also highly needed by the growing mining and agricultural sector in the region. In Namibia, for example, groundwater is the only source of drinking water for the inhabitants of the Kalahari (Wanke et al., 2008).

Studies such as Lerner et al. (1990) showed that tracer and empirical methods often result in different values for a given area. Such recharge disparities could have an implication on the actual groundwater availability. Particularly in arid and semi-arid areas, recharge amounts are usually small in comparison with the resolution of the investigation methods (Allison et al., 1984). Scanlon et al. (2006) also reported that in semi-arid and arid regions, the CMB method applied in an area of 40–37400 km^2 resulted in the recharge rates that vary between 0.2–35 mm/yr, representing 0.1–5% of long-term average rainfall. It is clear that CMB method depends on accurate measurement of dry and wet chloride from precipitation. It is also important to note that in arid and semi-arid areas, classical water balance methods could under- or over- estimate recharge due to their dependence on specific meteorological variables such as temperature and rainfall alone, while the effectiveness of recharge contribution to groundwater storage could also depend on the aquifer characteristics such as porosity and permeability. In this regard, even short duration rainfall with high intensity, could allow for recharge to take place if favourable hydrogeological condition exist in an area. Owing to the arid and semi-arid climatic conditions, especially in Namibia, Botswana, and the western parts of South Africa and Zimbabwe, the possibility of recharge occurrence from rainfall is very low, and hence, places a high value on groundwater resources than humid regions. In these areas, groundwater recharge may be limited and probably localized to line and point sources such as through streambeds and dam basins (Scanlon et al., 2002; Xu and Beekman, 2003). The specific focus of this paper is to highlight the degree of recharge variation based on the available documents and scientific literature. This work may, therefore, contribute to the application of water resources management in the region. In this very deprived and sensitive region, as a result of dominantly arid and semi-arid climate, people face droughts very often and depend on groundwater resources for their prosperity and even survival. Evaluating recharge estimation methods applied to groundwater recharge, is, therefore, a crucial tool for better groundwater management.

1.1. Site description

The Southern African region falls under the subtropical climatic zone that has complex air circulation dynamics as a result of the occurrence of the inter-tropical convergence zone (ITCZ), subtropical high pressure zones (SHPZ) located on the South Indian Ocean, Kalahari and South Atlantic Ocean high pressure, and the southern temperate zone (STZ) characterized by low pressure cold front from Antarctic. These pressure cells seasonally change positions and create strong variability in the rainfall amount with less than 100 mm/yr in the western part of South Africa, large parts of Namibia and Botswana. However, some areas of the region receive high rainfall with more than 1200 mm/yr, such as the eastern part of Zimbabwe and Eastern South