Stormwater harvesting using aquifer storage, case of Zeekoe Catchment in Cape Town, South Africa

Récolte des eaux pluviales dans un aquifère, cas du captage de Zeekoe au Cap, Afrique du Sud

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RÉSUMÉ

Les principaux réservoirs fournissant de l'eau à la ville de Cape Town (CCT) en Afrique du Sud devraient fournir une demande allant jusqu'à 2020-2023 (DWS, 2014). L'approvisionnement en eau des réservoirs a été sérieusement mis à l'épreuve par la sécheresse prolongée de 2015 - 2018 et la ville était menacée de risque de tarir les robinets en 2018. Ces sécheresses devraient se reproduire fréquemment à l'avenir, CCT étudie maintenant des ressources en eau alternatives telles que l'eau de mer, les effluents d'eaux usées traitées, l'augmentation des systèmes d'eaux de surface et des eaux souterraines existants. Cette étude a examiné les perspectives de collecte et de réutilisation des eaux pluviales en utilisant des bassins d'eaux pluviales servant de cellules d'infiltration afin de transférer les eaux pluviales vers un stockage aquifère afin d'accroître les ressources en eaux souterraines. L'étude a déterminé que les 61 bassins d'eaux pluviales disponibles dans le bassin versant de Zeekoe, adaptés pour améliorer le transfert des eaux de surface aux nappes souterraines, augmenteraient les ressources en eaux souterraines d'environ 9 à 12 Mm^3 / an (augmentation d'environ 30%).

ABSTRACT

The major reservoirs that supply water to the City of Cape Town (CCT) in South Africa are projected to provide for demand up to between 2020 – 2023 (DWS, 2014). The water supply from the reservoirs was severely tested by the prolonged drought of 2015 – 2018, and the city was threatened with the possibility of taps running dry in 2018. With such droughts expected to reoccur frequently in future, coupled with increasing population and raising living standards, CCT is now considering alternative water resources such as seawater, treated wastewater effluent, augmentation of existing surface water systems and groundwater. This study investigated the prospects for stormwater harvesting (SWH) and reuse using stormwater ponds functioning as infiltration cells to transfer stormwater to aquifer storage for augmentation of groundwater resources. The study determined that the 61 stormwater ponds available in the Zeekoe Catchment adapted to enhance surface to groundwater transfer would increase the groundwater resource by about 9 – 12 Mm^3 / year (about 30% increase).

KEYWORDS

Aquifer storage, Cape Town, Stormwater harvesting, South Africa, Zeekoe Catchment

1 INTRODUCTION

South Africa is a semi-arid and water-stressed country that heavily relies on surface water from unevenly distributed rainfall with a Mean Annual Precipitation (MAP) of 450 mm (Pitman, 2011). The corresponding streamflow in the rivers is relatively low with a Mean Annual Runoff (MAR) of 50,000 Mm^3 (about 3% of MAR in the Congo River) (Pitman, 2011). With the surface water resources in South Africa almost fully developed and utilised, it has been projected that there would be a gap between water demand and supply of some 17% by 2030 unless there is a meaningful change in water supply and use patterns (DWA, 2008). In the City of Cape Town (CCT), the major reservoirs for water supply are projected to provide for demand up to between 2020 – 2023 (DWS, 2014). The water supply from the reservoirs was severely tested by the prolonged drought of 2015 – 2018, which exposed the considerable vulnerability and limitations of the available surface water sources. The prolonged drought threatened the CCT with the possibility of taps running dry in 2018. With such droughts expected to reoccur frequently in future, coupled with increasing population and raising living standards, CCT is now considering alternative water resources such as seawater, wastewater effluent, augmentation of existing surface water systems and groundwater. Over the last three decades since 1990, new innovations of stormwater management with prospect of re-use have emerged, and suitability of these approaches in South Africa has been the subject of research at the University of Cape Town, South Africa (Armitage *et al.*, 2013). This study investigated the prospects for stormwater harvesting (SWH) and reuse using stormwater ponds functioning as infiltration cells to transfer stormwater to aquifer storage for augmentation of groundwater resources.

2 STUDY AREA AND METHOD

2.1 Study area

The Zeekoe Catchment (Figure 1) was chosen as the study area as it is particularly well located in a section of Cape Town with suitable features for Managed Aquifer Recharge and Recovery (MAR&R) *i.e.* availability of large unconfined aquifer that ranges between 20 and 55 m deep, pervious soils (sandy soils) and reasonably flat terrain (catchment slopes less than 3%). The catchment also had several stormwater ponds (Figure 1) with potential to be adapted to promote surface to groundwater transfer.

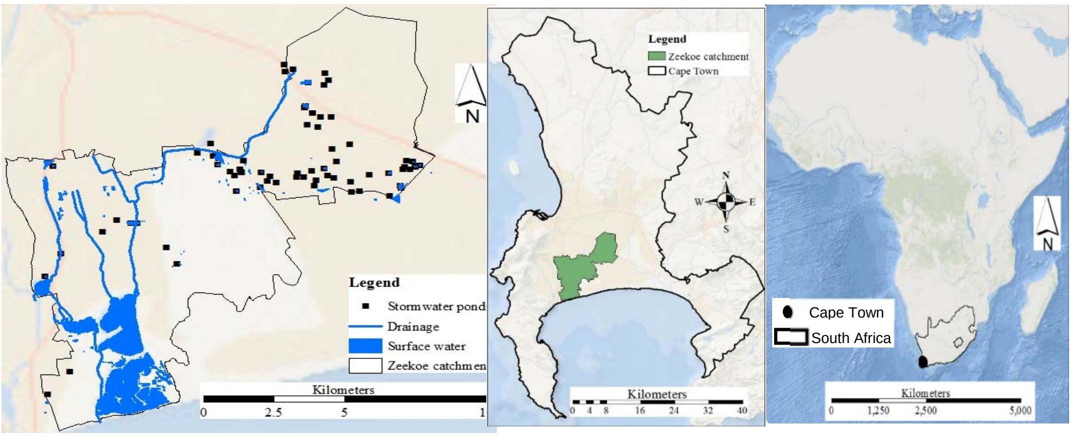

Figure 1 Location of Zeekoe Catchment in Cape Town, South Africa

2.2 Method

PCSWMM was used to model the hydrological and urban drainage processes in the Zeekoe Catchment with a view to assess the potential for stormwater transfer to groundwater storage with enhanced infiltration being primarily carried out in the existing stormwater ponds. Since PCSWMM did not have ordinary infiltration cells suitable for MAR, the study used the available bio-retention cells as the most suitable option that would also blend well with the stormwater pond environment. Thus the modeling of surface to ground transfer with modification of the existing stormwater ponds to function as infiltration cells was implemented using elements borrowed from bio-retention cell. However, PCSWMM mainly focuses on urban drainage with limited capacity to model abstraction of groundwater. The modelling of groundwater abstraction was implemented in MATLAB with a hybrid optimization approach that solves the two-dimensional steady-state partial differential groundwater flow equation commonly known as the Richard's equation (Richards, 1931). The hybrid optimisation approach combines genetic algorithms (GA) with some local search methods to solve the groundwater flow equations with a time step component (Mahinthakumar & Sayeed, 2006).

3 RESULTS AND DISCUSSION

3.1 Estimation of the supplemental groundwater resource

The summary of results from modelling the catchment hydrological and urban drainage processes show that the mean annual values for evaporation, evapotranspiration, surface runoff and infiltration for the cases of pre-construction and post-construction are as presented in Figure 2.

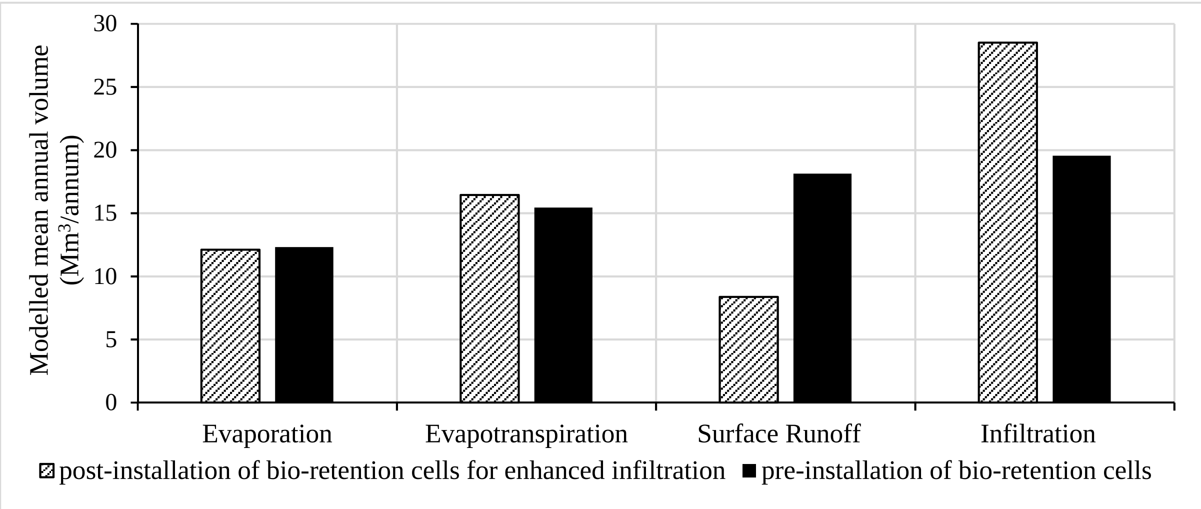

Figure 2 Comparison of existing and post-modification to bio-retention

As shown in Figure 2, the hydrological model indicated significant infiltration even before adoption of stormwater ponds to bio-retention cells. This can be attributed to large sections of the study area with rural farmland characteristics where natural recharge takes place. The model also shows that the 61 stormwater ponds available in the Zeekoe Catchment adapted to enhance surface to groundwater transfer would increase the groundwater resource by about 9 – 12 Mm^3 / year (about 30% increase).

3.2 Groundwater abstraction

The modelling of the groundwater abstraction in MATLab was implemented in two main steps, *i.e.* a manual trial and an optimisation process. The manual trial consisted of initially placing four boreholes per pond randomly around the stormwater ponds and each simulated with a groundwater abstraction rate of 5.8 L/s as determined in a trial section. The location, number of boreholes and abstraction rates were then adjusted until the flow fields started to come from the stormwater ponds. An optimisation procedure was then implemented with a genetic algorithm as proposed in Mahinthakumar & Sayeed, (2006) to provide the final borehole positions and abstraction rates. The modelled phreatic flow field for a section of the catchment showing the flow paths from the ponds to the proposed abstraction boreholes is presented in Figure 3.

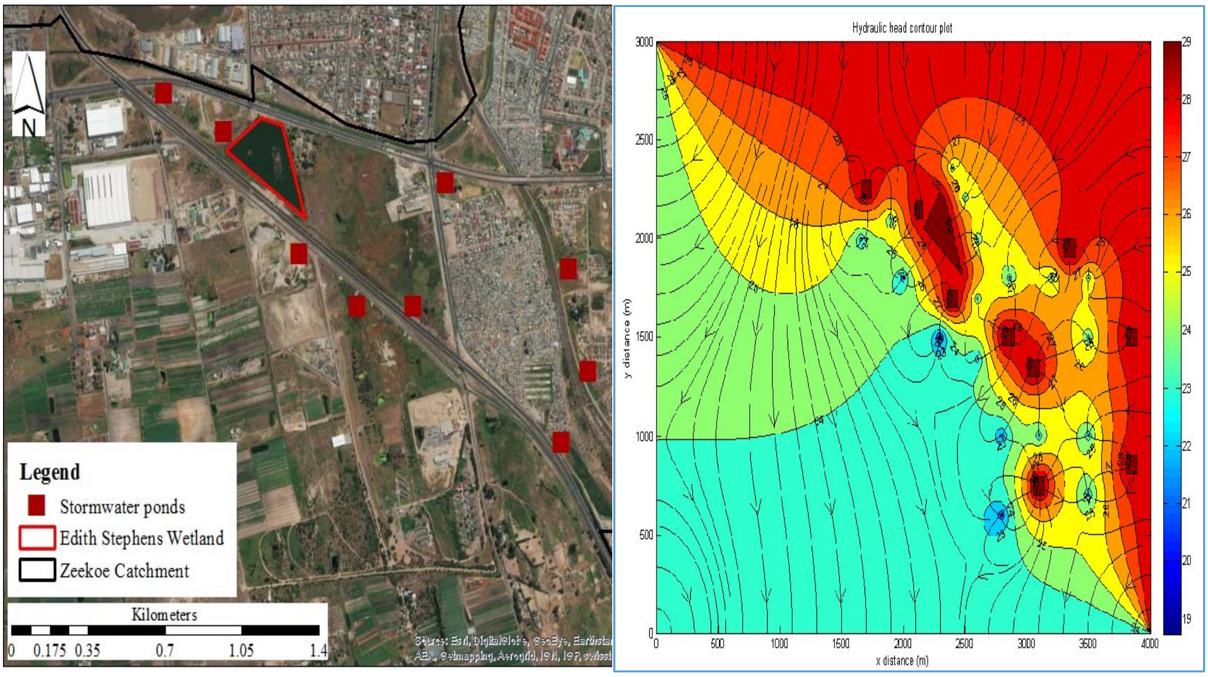

Figure 3 Modelled phreatic flow fields from the stormwater ponds to the boreholes

It was determined that depending on the aquifer parameters in the Zeekoe catchment *i.e.* conductivity, porosity and aquifer depth, the abstraction rates per borehole ranged from 3.5 – 8.1 L/s with a total of 140 boreholes to ensure that the flow fields were drawn largely from the areas around the stormwater ponds. When the abstraction rates increased beyond these values, the groundwater flow fields started drawing from areas outside the pond region.

4 CONCLUSIONS

This study has contributed to the debate on the alternative water resources for a water scarce City of Cape Town by considering the possibilities of stormwater harvesting (SWH) from groundwater storage at a catchment scale. The factors that were determined to be important and needed to be considered for the efficacious application of this approach included *inter alia* the availability of storage, the catchment characteristics (terrain, soil types, level of development, population density), and seasonal availability of the stormwater resource (winter or all year rainfall). Generally, SWH from groundwater storage seems to be a feasible option for water supply to Cape Town. Besides being a supplementary water resource, it provides additional benefits such as large storage that minimise loss of stormwater resource, flood control and stormwater quality improvement.

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