Introduction

- Dar es Salaam City, a home of over 4 million people, is located on the coast of Indian Ocean.
- The city depends for over 50% on local groundwater resources.

Problem setting

- The current groundwater abstraction under natural infiltration is about 184 mm (equivalent to 71.39 x 10^6 m^3/year) indicating that only 16.5% of the long-term average annual precipitation of 1114 mm ends up as groundwater recharge (Mjewa et al., 2011).
- The water balance of the catchment suggests for the average sustainable yield (calculated as 40% of natural groundwater recharge) a value of 28.56 x 10^6 m^3/year.
- The current groundwater abstraction is approximately 69.3 x 10^6 m^3/year and such overexploitation of groundwater usually results in a rise of the freshwater-saltwater interface and lateral seawater intrusion in a coastal aquifer, and thus degradation of groundwater quality.

Objectives of the study

- To assess the long term vulnerability of the water supply, including water quality, and the potential to increase the yield of the aquifer through artificial groundwater recharge (AGR).

Methodology

- The assessment of the potential for AGR included the evaluation of the dynamics of groundwater flow and recharge, and consideration of the options for artificial recharge devices that can be used. A primary concern was to understand the hydrological variability within the aquifers, as well as to identify potential sources of water for artificial recharge.
- Based on meteorological data, groundwater recharge was estimated using a soil moisture balance. Calculations with monthly meteorological data were used for the period 1971–2009.

Groundwater quality analysis

- From 124 groundwater samples analysed, groundwater is mainly affected by three factors: seawater intrusion due to aquifer overexploitation, dissolution of calcite and dolomite in recharge areas, and nitrate pollution mainly caused by the use of sewage discharge systems (pit latrines and septic tanks). High enrichment of Na^+ and Cl^- gives an indication of seawater intrusion into the aquifer as also supported from the Na–Cl signature on the Piper diagram. The boreholes close to the coast have much higher Na/Cl ratio values than the boreholes located further inland. The latter have a major ion composition characteristic of fresh and slightly altered groundwater (Ca-Mg-HCO3-). The dissolution of calcite and dolomite in recharge areas results in Ca-HCO3 and Ca-Mg-HCO3 groundwater types. Ca^2+ and Na^+ exchange causes chalcedony enrichment (Na–HCO3 type). Chloride (Cl^-) concentration shows general increase down gradient to the east towards the coast. Cl^- values range from 6.4 mg/l to 15,478 mg/l.

Groundwater hydrogeochemical analysis

- The AGR reservoir consists of two aquifers:
  i. Unconfined sand aquifer (-10 m). Average transmissivity and hydraulic conductivity is 34 m^3/d and 1.58 m/d respectively.
  ii. Lower semi-confined sand aquifer (5-50m). Average transmissivity and hydraulic conductivity is 28.56 m^3/d and 2.14 m/d respectively.
- Aquifers are separated by a clay aquitard (1-30m) except in the area close to the ocean.
- The general groundwater flow direction is towards the sea.

Hydrogeological suitability and natural groundwater recharge

- Permeable strata are available at shallow and medium depths. Due to the sandy nature of the subsoil in many parts of the city, sinking of boreholes is easy and this has led to the increased supply of groundwater. The area is under agriculture and irrigation activities. Two aquifers have been considered for further investigation: i) replevment on the aquifiers was done to the aquifers; ii) recharge of groundwater from the river to the aquifer is scarce.

Artificial groundwater recharge to augment natural replenishment

- Groundwater is the major resource of water for Dar es Salaam which has a high and expanding population of over 4 millions. Groundwater level has decreased since 1976 when boreholes driling began to expand quickly following the weakening of the surface water supply and the rapid growth of the city and its suburbs. Over 7,500 active boreholes/wells exist. In view of increasing reliance on groundwater and prolonged aquifer over-exploitation, further lowering of groundwater levels is expected. In order to ensure the sustainability of the aquifer, artificial groundwater recharge (AGR) is considered as one of the options to increase groundwater storage.

- Artificial groundwater recharge for artificial groundwater recharge in Dar es Salaam

  i. Non-committed surface runoff that flows out of the area (about 10% of the rainfall).
  ii. Grey water (from baths, kitchens, washing machines and sinks) accounting for over 50% of the outflow from homes. Grey water has less pathogens and nitrogen compared to the wastewater from the toilets and does not require expensive treatment, and is a potential resource for AGR.

- Available wastewater treatment techniques in Dar es Salaam

  Constructed wetland at University of Dar es Salaam (Mbashita et al., 2000): The field tests were conducted at low and high infiltration rates of 0.27 m/h and 2.3 m/h respectively. Treatment effectiveness: high mean removal efficiencies: 80% for suspended solids (SS), 66% for CO2, 91% for faecal coliforms (FC) and 90% for the total coliforms (TC) achieved at the low infiltration rate.

  Grey water treatment system (Kagungu and Kocanda, 2010): The treatment system is cost-effective; it consists of concrete boxes placed over each other, filled with coarse porous material and planted with plants. The system purifies grey water as it percolates through it and at the same time provides a vertical space for growing plants (Typha latifolia and Scirpus sp.) used for wastewater treatment purposes. Water treated is best for irrigation as well as groundwater recharge. The system is similar to the treatment system built in Gotland, Sweden.

- Recharging techniques

  Artificial groundwater recharge in Dar es Salaam coastal aquifer can be attained by several methods depending on the local topographical, geological and soil conditions. It can employ an integrated series of techniques, which, for example, can include damming the gullies of minor streams, constructing subsurface dikes and/or percolation tanks along their tributaries, contour bunding and trenching on slopes and establishing farm ponds. Terracing and forestation of open spaces, which help to retain runoff and increase infiltration, may also form part of an integrated basin-scale water resources development plan. On channel systems such as constructing a dam or weir or creating channels over a highly permeable area in an unsaturated zone can be as well useful. The pooling of water over a recharge zone allows a greater rate of infiltration when compared to a flowing surface. This method can be particularly useful in ephemeral river systems to maintain a constant head of water recharging the aquifer throughout the year.

Conclusion

- The coastal aquifer in Dar es Salaam is clearly overexploited. Utilizing runoff (which otherwise drains off) and grey water (which is otherwise disposed) will bring great benefits for improving groundwater levels (which have dropped due to overexploitation), providing a barrier for seawater intrusion and prevention of diseases and floods by deviating peak flows. By implementing AGR, excess water in the catchment area can be collected and allowed to infiltrate, to increase groundwater storage in rainy seasons to be utilized later in dry seasons.

Further research needs

- There is a need of establishment of a warning system for drop in piezometric head and the encroachment of seawater by placing of piezometers along the edge of the sea. Accordingly monitoring wells should be strategically established inland to monitor groundwater fluctuation and quality. By continuously monitoring the head and the water quality, it will be possible to detect some long-term trends and to devise management strategies.

- Detailed study is needed to determine sites and design structures for artificial groundwater recharge. Future work should also focus on designing a test programme which includes chemical and physical modeling of recharge options, and measurement of recharge rates. Close follow-up of infiltrated water quality to prevent aquifer pollution is crucial.

References