Journal of African Earth Sciences 55 (2009) 134–146

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Groundwater exploitation and hydraulic parameter estimation for a Quaternary aquifer in Dar-es-Salaam Tanzania

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ARTICLE INFO

Article history:
Received 3 July 2008
Received in revised form 2 March 2009
Accepted 25 March 2009
Available online 5 April 2009

Keywords:
Dar-es-Salaam
Quaternary aquifer
Groundwater exploitation
Pumping test
Specific well capacity
Hydraulic parameters

ABSTRACT

The fact that groundwater exploitation has largely increased since 1997 in the Dar-es-Salaam aquifer, calls for a directed attention towards possible problems of aquifer overexploitation that may arise in the near future. Hydraulic parameters are important for developing local and regional water plans as well as developing numerical groundwater flow models to predict the future availability of the water resource. The determination of aquifer parameters through pumping tests has become a standard step in the evaluation of groundwater resource potential. The pumping tests in the study area were conducted in August 2004 and August 2005, where 39 boreholes were tested out of 400 visited. In the study area there are over 1300 recorded boreholes drilled by Drilling and Dam Construction Agency (DDCA) by the year 2005. Total groundwater exploitation in the study area was estimated at 8.59×10^6 m^3/year, based on yield data collected during the 2004–2005 field campaigns. The pumping tests included single-well tests and tests with measurements on the pumping well and at least one observation well. The tests were conducted for 6 h and 30 min. The pump was shut down after 6 h of pumping and the remaining 30 min were used for recovery measurements. The pumping test analysis methods used include: Neuman type curve matching and Walton type curve matching, checked by specific well capacity assessment and Thiem–Dupuit/Thiem's method. The curve-matching results from the aquifer tests show the following parameters: an average transmissivity and hydraulic conductivity of 34 m^2/d and 1.58 m/d, respectively for the unconfined aquifer; the semi-confined aquifer has an average value of 63 m^2/d and 2.14 m/d for transmissivity and hydraulic conductivity, respectively. For the case of the storativity, the unconfined aquifer has an average elastic early-time storativity of 0.01, while the lower aquifer has an average storativity of 3×10^{-4}. Specific well capacity method and Thiem–Dupuit/Thiem's method confirm results for transmissivity and hydraulic conductivity of the semi-confined aquifer, while values for the unconfined aquifer are somewhat larger (by a factor of 2–3). The hydraulic parameters calculated appear to reasonably agree with the geological formation of the aquifers, as deduced from borehole descriptions.

1. Introduction

Groundwater flow varies in space and time and is dependent on the hydraulic properties of the rocks and the boundary conditions imposed on the groundwater system (Stallman, 1971). Hydraulic parameters (transmissivity, hydraulic conductivity and storativity) are important for developing local and regional water plans and developing numerical groundwater flow models to predict the future availability of the water resource. A pumping test can also indicate disturbing factors such as lateral flow boundaries, hydraulic continuity, constraints of fracture flow, and recharge. All of these are important to understand in order to establish proper management of the groundwater resources. From the water exploitation perspective, the "test pumping" is the best method by which to size and establish the optimal capacity and depth setting of the pump, as well as to establish system storage and operational needs. Proper pump sizing and depth selection can provide considerable savings to a water system over the lifetime of the well, through reduced power consumption and maintenance costs. On the other hand, a "pumping test" is a scientific experiment aimed at deducing hydraulic characteristics.

The study covers part of Dar-es-Salaam and Kisarawe areas. It focuses on the hydrogeological characteristics of the unconsolidated sediments of Quaternary age, which form the major aquifer in the coastal area of Dar-es-Salaam region. Dar-es-Salaam is the largest urban centre in Tanzania, with a population of about 3 million. The study area is located at latitudes 6°44′S to 7°00′S and longitudes 39°00′E to 39°19′E, with an area of about 700 km^2 (Fig. 1). In this study, emphasis was given to hydrodynamic characteristics

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doi:10.1016/j.jafrearsci.2009.03.009

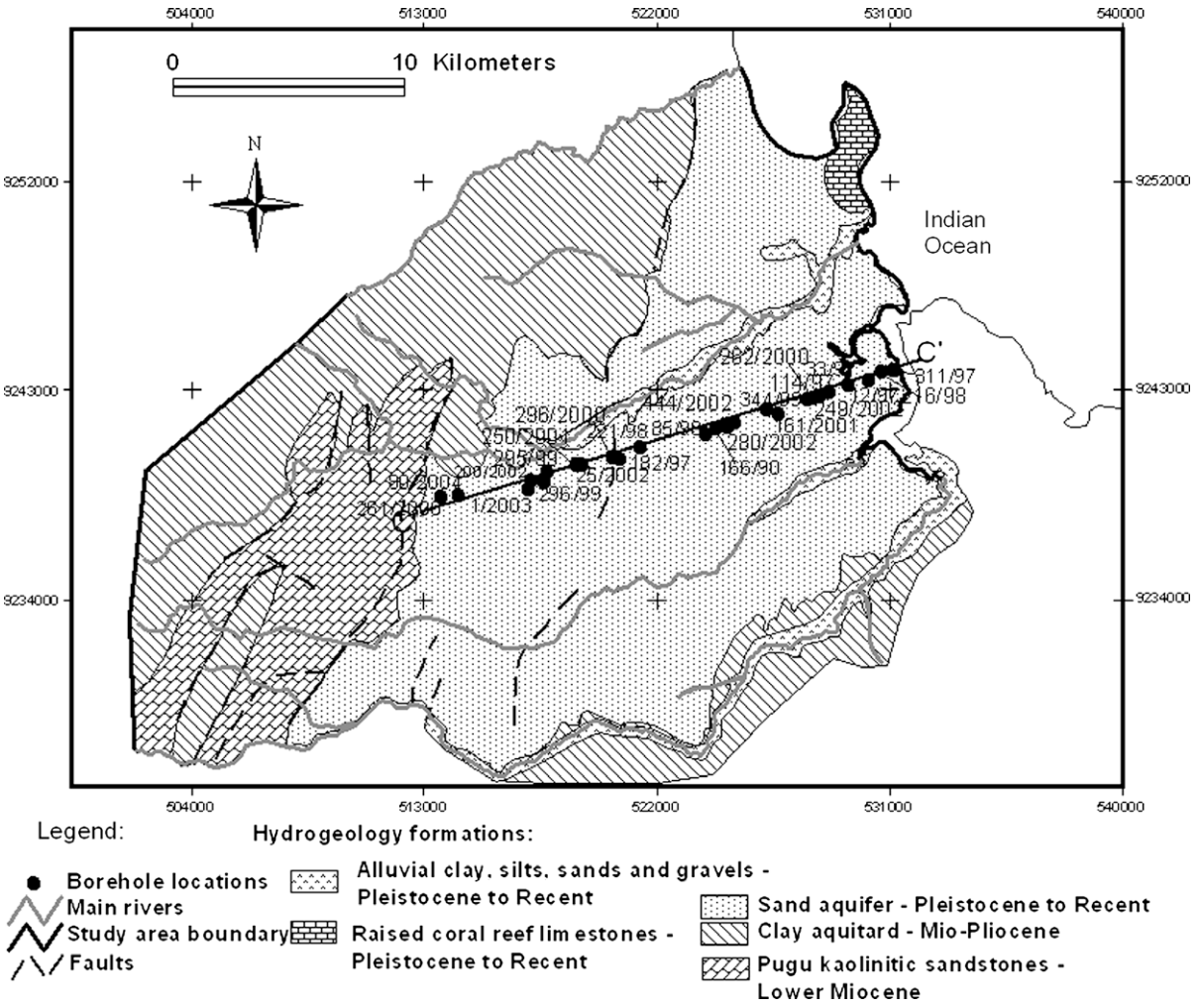

Fig. 1. Hydrogeological map of the study area with location of boreholes used in the cross section.

of the sand aquifers because such data are lacking in the study area. The pumping tests were conducted in August 2004 and August 2005, where 39 boreholes were tested out of 400 visited. In the area, there are over 1300 recorded boreholes drilled by Drilling and Dam Construction Agency (DDCA) by the year 2005. However, some of them are not operating due to either pump failure or high salinity. The pumping tests included single-well tests and tests with measurements on the pumping well and at least one observation well. The tests were conducted for 6 h and 30 min. The pump was shut down after 6 h of pumping and the remaining 30 min were used for recovery measurements. The purpose of the tests was to determine the hydraulic parameters, the productivity of each well and the interference each pumped well produced in surrounding wells. The computer program Infinite Extent, a Windows-based pump test analysis package, was used to analyze the pumping test data (Starpoint Software, 1996).

The pumping test analysis methods used include: Neuman type curve matching for constant pumping rate in the unconfined aquifer and Walton type curve matching for constant pumping rate in the semi-confined aquifer. The specific capacity method was also employed for calculating transmissivity from drawdown and pumping rate at steady state. Additionally, for the tests with measurements on both the pumping well and at least one observation well, Thiem–Dupuit's interpretation method was applied for tests in the unconfined aquifer and Thiem's method for tests in the semi-confined aquifer, both at steady-state flow. The resultant transmissivity estimates were then divided by the aquifer saturated thickness to obtain horizontal hydraulic conductivity values.

2. Hydrogeological settings of the study area

The study area comprises three major parts, distinguished by the geological formations outcropping: the central coastal plain with Quaternary fluviatile-deltaic sediments, the deltaic Mio-Pliocene clay-bound sands and gravels in the northwest and southeast and the Lower Miocene fluviatile sandstones of Pugu Hills in the west of the study area (see Fig. 1). The Quaternary deposits of Pleistocene to Recent periods have total thickness of approximately 150 m within Dar-es-Salaam City area. They overlay the deltaic deposits of Mio-Pliocene age, which consist of clay-bound sands and gravels, with a thickness around 1000 m (>740 m at Kimbiji borehole) (Kent et al., 1971); they can be considered as the base of the groundwater reservoir. Underlying the clay-bound sands and gravels are the kaolinitic Pugu Sandstones with a thickness of more than 1000 m, that are well developed in the central part of the Dar-es-Salaam embayment. However in Pugu Hills they are found with a thickness of only 300 m (Kent et al., 1971), since part of it, together with the clay-bound sands has been eroded to fill the Pleistocene coastal plain. The groundwater reservoir in Dar-es-Salaam area, in the coastal plain, mainly consists of two