Integrated hydrologic modeling as a key for sustainable development planning of urban water resources in the semi-arid watersheds of the Gaza Strip

Dissertation

zur

Erlangung des Doktorgrades (Dr. rer. nat.)

der

Mathematisch-Naturwissenschaftlichen Fakultät

der

Rheinischen Friedrich-Wilhelms-Universität Bonn

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Gaza, Palästina

Bonn, 2015

Abstract

This study demonstrates the strength of using integrated hydrologic modeling in a sustainable urban water planning process. It provides a complete view of the urban water system of the Gaza Strip, quantifies the urban water budget interaction with sufficient spatial and temporal details, and supports realistic scenarios inferred from the decision-making agenda. This study comprises three main parts. The first part aims to quantify the impact of urban area expansion on groundwater recharge and surface runoff by developing surface water modeling and investigating the response of watersheds to urban development. The second part provides a spatial-temporal assessment of potential impacts of urban area expansion on groundwater level concerning the link between surface and groundwater models. The third part promotes an integrated hydrologic modeling as a key for sustainable urban water resources considering the coupling of surface water, groundwater flow, and solute transport models.

In the first part, a new spatial evaluation for assessing the impact of urbanization was applied for the semi-arid watersheds intersecting with the Gaza coastal aquifer. The SWAT model was calibrated and validated in a semi-automated approach for stream flow in the main watersheds. The results show that the model could simulate water budget components adequately within the complex semi-arid watersheds. Linear relationships between the change in urban area and the corresponding change in surface runoff or percolation were concluded for the urbanized subbasins. The urban-surface runoff index (USI) and the urban-percolation index (UPI) were developed to represent a micro-level evaluation of different urban change scenarios in the subbasins. The global urban-surface runoff index (GUSI) and the global urban-percolation index (GUPI) were derived as macro-level factors reflecting the influence on the overall Gaza coastal aquifer due to urban area expansion.

In the second part, a 3-D groundwater flow model was developed using MODFLOW-USG to investigate the groundwater levels within the Gaza coastal aquifer. Recharge estimation is based on a comprehensive approach including the connection to the surface water model (SWAT) for determining percolation from rainfall as well as detailed approaches regarding further recharge components. An unstructured grid (Voronoi cells) generated by MODFLOW-USG engine was used to reduce run time within complicated aquifer boundary conditions. The results indicate a very good fit between measured and simulated heads. Long-term forecasting (2004–2030) of the groundwater levels was carried out as an essential step to support realistic and sustainable water resources planning and decision making. The increasing built-up area was linked to the potential impacts of urban expansion relating to water supply quantities and groundwater recharge components. The percolation was reduced temporally and spatially in the forecasting period based on the projected built-up area as well as the urban-percolation index. Considering the current management situation, the annual groundwater level correlated negatively with the increasing built-up area; the regression line slope was -0.056 m/km^2 for the average groundwater levels while it became steeper at -0.23 m/km^2 in sensitive locations in the southern part of the Gaza Strip. The groundwater-level trend index was developed as a spatial indicator for the appropriate management alternatives that can achieve less negative trend index.

In the last part of this study, a coupling of surface water (SWAT), groundwater (MODFLOW) and solute transport (MT3DMS) models was performed to quantify surface-groundwater and quantity-quality interactions under urban area expansion. The results indicate a good fit between measured and simulated nitrate and chloride concentrations. The response of groundwater level, nitrate concentrations (related to human activities) and chloride concentrations (related to seawater intrusion) to urban area expansion and corresponding changes in the urban water budget were examined on a macro-scale level (the Gaza coastal aquifer domain). The potentials of non-conventional water resources scenarios, namely desalination, stormwater harvesting and treated wastewater reuse as well as an infrastructure performance scenario were investigated. In a novel analysis, groundwater improvement and deterioration under each scenario were defined and discussed in spatial-temporal and statistical approaches. The quality deterioration cycle index was estimated as the ratio between the amounts of low and high quality recharge components within the Gaza Strip boundary predicted for year 2030. The improvement index for groundwater level (IIL) and the improvement index for groundwater quality (IIQ) were developed for the scenarios as measures of the effectiveness toward sustainable groundwater planning.