Assessment of nitrate contamination of groundwater using lumped-parameter models

Lubna Hajhamad, Mohammad N. Almasri*

College of Engineering, Department of Civil Engineering, An-Najah National University, P.O. Box 7, Nablus, Palestine

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ABSTRACT

In this paper, lumped-parameter models (LPMs) were developed and utilized to simulate nitrate concentration in the groundwater of Gaza City and Jabalia Camp (GCJC) in the Gaza Coastal Aquifer (GCA) in Palestine. In the GCJC area, nitrate levels exceed the maximum contaminant level (MCL) of 10 mg/L NO_3-N (45 mg/L NO_3) in many wells. Elevated nitrate concentrations in the groundwater of GCJC area are due to the disposal of untreated wastewater, the existence of heavy agriculture in the surrounding areas, and the use of cesspits for wastewater disposal. The developed LPMs utilize monthly time steps and take into consideration all the sources and sinks of water and nitrate in the study area. The main outcomes of the LPMs are the average temporal water table elevation and nitrate concentration. In order to demonstrate LPMs usability, a set of management options to reduce nitrate concentration in the groundwater of the study area were proposed and evaluated using the developed LPMs. Four broad management options were considered where these options tackle the reduction of nitrate concentration in the lateral inflow, rehabilitation of the wastewater collection system, reduction in cesspit usage, and the restriction on the use of nitrogen-based fertilizers. In addition, management options that encompass different combinations of the single management options were taken into account. Different scenarios that correspond to the different management options were investigated. It was found based on the LPMs that individual management options were not effective in meeting the MCL of nitrate. However, the combination of the four single management options with full rehabilitation and coverage of the wastewater collection network along with at least 60% reduction in both nitrate concentration in the lateral inflow and the use of nitrogen-based fertilizers would meet the MCL constraint by the end of the management period.

1. Introduction

Many regions all over the world depend entirely on groundwater resources for various uses (Babiker et al., 2003; Thirumalaivasan et al., 2003). However, the population growth and the increase in demand for water and food supplies place an increasing stress on the groundwater quantity and quality (Joosten et al., 1998; Lewis and Bardon, 1998; Thirumalaivasan et al., 2003; De Santa Olalla et al., 2007; Tait et al., 2008) where over-abstraction depletes the available quantity of groundwater (Ataie-Ashtiani, 2007). In addition, the increase in demand for food supplies may lead to groundwater contamination by nitrate since the major contributor to nitrate contamination in groundwater is the use of nitrogen-based fertilizers associated with cropping activities (Konikow and Person, 1985; Shamrukh et al., 2001; Wolf et al., 2003; Almasri and Kaluarachchi, 2005; Mao et al., 2006; Tait et al., 2008). Elevated nitrate concentrations in drinking water can cause methemoglobinemia in infants and stomach cancer in adults (Lee et al., 1991; Wolfe and Patz, 2002). Because of that the US Environmental Protection Agency (US EPA) has established a maximum contaminant level (MCL) of 10 mg/L NO_3-N (US EPA, 2000).

Sources of groundwater contamination by nitrate can be classified into point and non-point sources. Non-point sources of nitrogen include fertilizers, manure application, leguminous crops, dissolved nitrogen in precipitation, irrigation return-flows, and dry deposition. Point sources such as septic systems and cesspits can also be major sources of nitrate pollution (Joosten et al., 1998; Stournaras, 1998; Mitchell et al., 2003; Babiker et al., 2003; Almasri and Kaluarachchi, 2005; Wolf et al., 2003; Santhi et al., 2006; Tait et al., 2008).

Nitrogen applied through fertilizers or manure is converted to plant-available-nitrate by bacteria living in the soil. The growing plants uptake part of this nitrate. The nitrate that is not taken up by crops, immobilized by bacteria into soil organic matter or converted

* Corresponding author. Tel: +972 9 2394960; fax: +972 9 2345982.
E-mail address: mnmasri@najah.edu (M.N. Almasri).

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