SIMULATION OF NITRATE CONTAMINATION IN LAKE KARLA AQUIFER

TZIATZIOS G., SIDIROPOULOS P., VASILIADES L., MYLOPOULOS N. and LOUKAS A.

Laboratory of Hydrology and Aquatic Systems Analysis
Department of Civil Engineering, School of Engineering, University of Thessaly, Pedion Areos
38334 Volos, Greece
E-mail**:** nikitas@civ.uth.gr

ABSTRACT

Lake Karla aquifer's area is an agricultural region with intense and extensive cultivation of water demanding crops. The main crops are cotton, maize and wheat. The intense and extensive agricultural activity leads to excessive use of fertilizers. The extensive application of fertilizers results in the degradation of groundwater resources quality. The study area faces problems of nitrate pollution on groundwater resources. In this study, a modeling procedure has been undertaken for the evaluation of nitrate pollution in the groundwater. The surface hydrology model UTHBAL has been firstly applied. The UTHBAL model is coupled through the simulated groundwater recharge with the MODFLOW model, which simulates the groundwater flow. Then, the transport model MT3DMS coupled with the MODFLOW model has been used to simulate the nitrate contamination. Specific GIS modules have been used for the division of study area into Municipal Districts. The crops, the nitrate loading and leaching have been estimated for each Municipal District. The simulation period started on 01/06/1995 and ended on 01/09/2007. Nitrate concentrations from 11 observation wells on 01/06/1995 have been used as initial concentrations in the modeling. The transport model MT3DMS has been applied as a transient model. A sensitivity analysis has also applied indicating that the nitrate leaching is the most uncertain parameter. Therefore, the nitrate leaching rate has been used as calibration parameter of the transport model. The results indicate that the most contaminated areas are located in the south and east part of the study area.

Keywords: Nitrate contamination**,** groundwater quality simulation, nitrate transport, diffuse pollution, MODFLOW, MT3DTS, UTHBAL

1. Introduction

The intensified use of chemical compounds for urban, industrial and agricultural purposes has a negative impact on groundwater contamination (Liedl *et al.,* 2005*).* The nitrate pollution by agriculture constitutes a special case for groundwater quality degradation. Nitrogenous fertilizers are widely used in agricultural activities to increase crop productivity as well as the quality of the crop products. As Babiker and his associates (Babiker *et al.,* 2004) mention nitrate constitute one of the main chemical substances which are used in agriculture and have as a consequence the high rate of nitrate infiltrating into groundwater resources. Nitrate leaching has been recognized as the main agricultural source of groundwater contamination, which is a globally growing problem due to the population growth which increases the demand for food supplies. No efficient solution for the reduction of pollutants came from organic and chemical compounds in groundwater has been found (Qiu *et al.,* 2011; Liedl *et al.,* 2005). According to Filintas (Filintas, 2007), the nutrients loss through leaching is determined mainly by interactions soil - nutrients and the climatic changes.

Thessaly, the second largest plain in Greece occupies an area of about 4,000 km^2 where the main occupation is the agriculture activity. The intense cultivation implies a large amount of fertilizers, pesticides and other agrochemicals applied in the field. Cotton, maize and wheat are

the main crops cultivated in the study area. These crops are water demanding crops and they are crops in which large amounts of nitrogenous fertilizers are applied. The application of large amounts of fertilizers lead to the degradation of groundwater quality. Lake Karla's aquifer, with an area of 500 km^2, is a typical case of groundwater nitrate contamination (Loukas *et al.,* 2006, Sidiropoulos *et al.,* 2008, Giannouli and Antonopoulos, 2015).

In this study, a transient simulation model of nitrate transport and dispersion of Lake Karla's aquifer has been applied. For this reason, a modeling system of three coupled models have been developed and applied. These models are: a monthly conceptual hydrological model (UTHBAL) for the assessment of surface runoff and groundwater recharge, a groundwater simulation model (MODFLOW) and a groundwater transport and dispersion simulation model (MT3DMS).

2. Study area

Lake Karla watershed covers an area of 1171 km^2 and located in the eastern part of Thessaly region of central Greece (Fig.1). The region is characterized by its continental Mediterranean climate where. The average temperature is 16 -17°C and the mean annual precipitation is 560 mm. Cultivated area in the Lake Karla basin covers 375,5 km^2 approximately (Sidiropoulos *et al*., 2015).

The recent Quaternary deposits occupy the largest part of the plain, which consist of variable grain size materials, fluvial or lacustrine deposits, originating from Lake Karla and the surrounding torrents. Karstic formations extended in the south of mountain Mavrovouni and Halkodonio. Finally, impermeable formations cover northern of mountain Mavrovouni, Ossa, Halkodonio. The bedrock of Lake Karla's basin is composed by schist, gneiss and marbles (Constantinidis, 1978).

3. Methodology

The initial step of methodology was the identification of the Municipal Districts with the use of Geographical Information System (GIS). Then, the crops cultivated in the study area have been recorded and finally, the nitrate loadings and leaching are estimated for each municipal district (Figure 2). The cultivations were classified according to their types and the cultivated area for each Municipal District was estimated. The Municipal Districts of Nikaia and Galini due to the very small area extent have been incorporated in the municipal districts of Halki and Platykampos, respectively. (SIRRIMED, 2013).

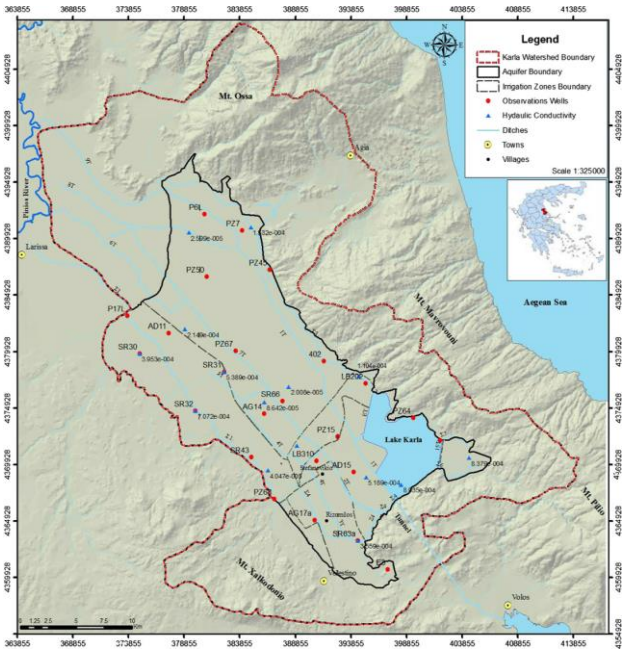

Figure 1: Map of Lake Karla basin indicating the study area

3.1. Modeling System

The modeling system consists of three models: a monthly conceptual hydrological model (UTHBAL) for the assessment of surface runoff and groundwater recharge, a groundwater simulation model (MODFLOW) and a groundwater transport and dispersion simulation model (MT3DMS).

The UTHBAL model was calibrated using the monthly observed values of Lake Karla's basin runoff to Pagasitikos Gulf for the period October 1960 to September 2002 and was used to produce synthetic time series of runoff and groundwater recharge data for the Lake Karla watershed untill September 2007.

Lake Karla's region studied as single layer unconfined aquifer was approached with the use of a 12500 rectangular grids of 200 m X 200 m. Hydraulic conductivity is the calibration parameter of MODFLOW spatially distributed using the Simple Kriging method (Mylopoulos and Sidiropoulos, 2009). The surface inflows of the model were the surface recharge. The water withdrawals from the groundwater were obtained as outflows. Model's calibration and application has been presented in another paper (Sidiropoulos *et al*., 2013).

The MT3DMS model has been used for the contaminant transport and dispersion. The longitudinal dispersivity (a_L) was set to 20 m and the transverse dispersivity (a_T) value was equal to 0.1 which depend on geological material. These values have been taken from bibliographical sources for similar porous media (Gelhar et *al.,* 1992). According to SOGREAH (1974) the porosity was equal to 0.3 in the study area. Siarkos and his associates (Siarkos *et al*., 2013) estimated that 40% of the nitrate infiltrates the aquifer in the basin of New Moudania. A similar percentage was considered in the study case. The volume of nitrate leaching to the aquifer was calculated by:

$$\frac{\text{nitrate loading}\left(\frac{\text{kg}}{\text{day}}\right)*0{,}4}{\text{recharge}\ \frac{\text{mm}}{365\text{day}}\ *\ \text{cultivated area}\ (\text{m}^2)}$$

Nitrate concentrations of 1 June 1995 from 11 observation wells have been used as initial nitrate concentrations (Institute of Geology and Mineral Exploration, 2010). The spatial distribution of the initial nitrate concentrations has been found using the Simple Kriging method (Figure 2).

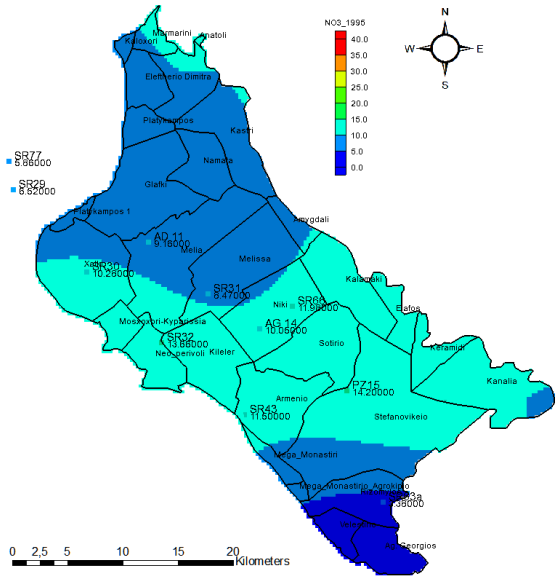

Figure 2: Distribution of initial nitrate concentrations in 1/06/1995.

3.2. Results

A sensitivity analysis has been performed to identify the most sensitive parameters affecting groundwater contamination. The sensitivity analysis indicated that the nitrate leaching parameter is the most uncertain parameter. As a result, the calibration was based on the nitrate leaching rate using a trial and error method. The final values of the simulated nitrate concentrations differ slightly from the observed values, ranging from 1,08 to 1,50 mg /l as presented in Figure 3.

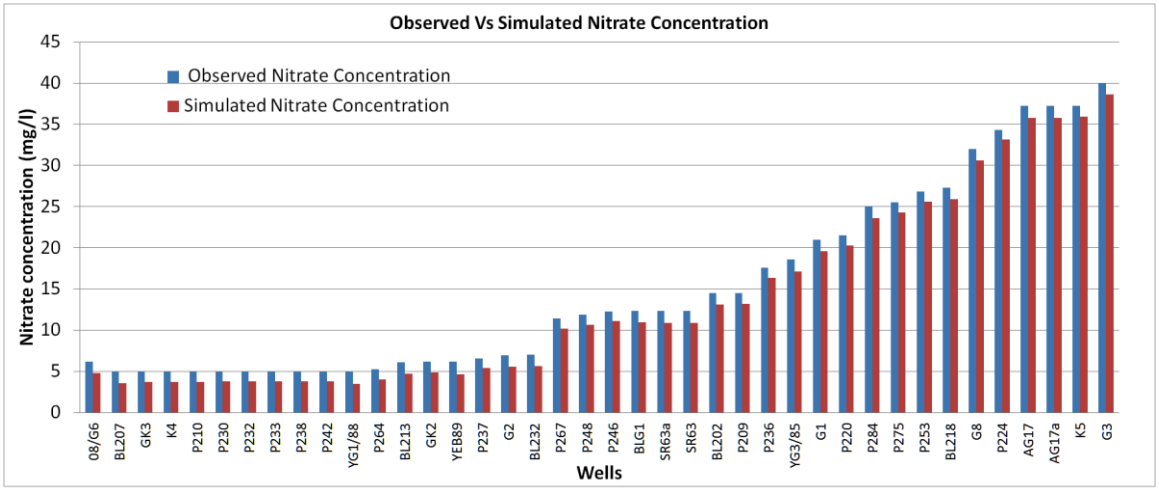

Figure 3: Comparison the observed towards to simulated nitrate concentrations

4. Conclusions

The results of this study indicated that the problem of nitrate contamination in the aquifer of Lake Karla is severe. It can be concluded that:

- The transport and dispersion coefficients (longitudinal (a_L) and the transverse dispersivity (a_T)) do not affect in the nitrate fate on groundwater resources.
- The sensitivity analysis indicated that the nitrate leaching is the most uncertain parameter in the transport model.

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