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Evaluation of the effects of climate and man intervention on ground waters and their dependent ecosystems using time series analysis

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SUMMARY

Groundwaters and their dependent ecosystems are affected both by the meteorological conditions as well as from human interventions, mainly in the form of groundwater abstractions for irrigation needs. This work aims at investigating the quantitative effects of meteorological conditions and man intervention on groundwater resources and their dependent ecosystems. Various seasonal Auto-Regressive Integrated Moving Average (ARIMA) models with external predictor variables were used in order to model the influence of meteorological conditions and man intervention on the groundwater level time series. Initially, a seasonal ARIMA model that simulates the abstraction time series using as external predictor variable temperature (T) was prepared. Thereafter, seasonal ARIMA models were developed in order to simulate groundwater level time series in 8 monitoring locations, using the appropriate predictor variables determined for each individual case. The spatial component was introduced through the use of Geographical Information Systems (GIS). Application of the proposed methodology took place in the Neon Sidirochorion alluvial aquifer (Northern Greece), for which a 7-year long time series (i.e., 2003–2010) of piezometric and groundwater abstraction data exists. According to the developed ARIMA models, three distinct groups of groundwater level time series exist; the first one proves to be dependent only on the meteorological parameters, the second group demonstrates a mixed dependence both on meteorological conditions and on human intervention, whereas the third group shows a clear influence from man intervention. Moreover, there is evidence that groundwater abstraction has affected an important protected ecosystem.

1. Introduction

It is widely concerned that climate change has already influenced present climate. This is likely to have even more effect on societies while human beings adapt themselves to the new climatic circumstances, i.e., new hardy cultivations are put into practice. In addition to the direct effects of climate changes, there are also implicit effects on other natural resources and especially on water resources. A typical example could be the case of an extreme drought period that affected an area, which has a direct effect on groundwater recharge and at the same time it brings an indirect negative effect mainly due to the excessive human use of water resources, in order to overcome the increased water demands through the drought period. Maneta et al. (2009) simulated two droughts of increasing intensity to investigate how farmers behave under rain shortfalls of different severity. Results showed that farmers react to rainfall shortages to minimize their effects on farm profits, and that the impact on farmers depends, among other things, on their location in the watershed and on their access to groundwater. Moustadraf et al. (2008) conducted a study on the impacts of climate changes on the coastal Chaouia aquifer in Morocco using numerical modeling. They concluded that the severe degradation of the groundwater resource is primarily related to intensive pumping during periods of drought. In such conditions, it is very hard to distinguish which of the effects on resources are more severe. As climate change is the most difficult factor to cope with, it is highly desirable for man to be able to predict the responses of water resources to external stresses so as to adapt management plans and land uses to the new anticipated circumstances.

Several approaches can be found in relevant literature, including both deterministic and stochastic approaches. Deterministic models mathematically describe water resources systems in a physical way. Model parameters are normally related to the characteristics of those physical systems. Their calibration requires a thorough understanding of the studied system and detailed historical observations, which are usually unavailable. Stochastic models do not pose such pre-requirements. They avoid the problem of mathematically describing the system processes, and instead they identify the statistical relationship direct from the reality.

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In the past decades, deterministic models have been coupled either with historical meteorological records or with outputs from climate modeling for simulating groundwater properties and predicting their future response. Such studies were carried out in different regions of the world. For instance, Candela et al. (2009) coupled the downscaled output from a Global Climate Model (GCM) to a groundwater numerical model to estimate the impacts of climate change and management practices on groundwater and their associated ecosystems. Thompson et al. (2009) used a numerical model coupled with four emission scenarios for the 2050s to study the hydrological impacts of climate change upon the Elmley Marshes, southeast England. Ranjan et al. (2009) used a simplified numerical model with limited data together with meteorological data from HadCM3 GCM model in order to simulate effects of climate change on the coastal fresh groundwater resources at the global scale. Chen et al. (2004) applied an analytical model to simulate the long term effects of climate change on the carbonate aquifer of Winnipeg Canada using historical records of precipitation and temperature data of 105 years. Brouyère et al. (2004) applied numerical modeling in the basin of Geer in Belgium and showed, according to the tested scenarios, that there will be a decrease in groundwater levels in Belgium in the future. They concluded that a trend of increasing temperatures, predicted by GCMs for this region, may reduce net recharge and affect groundwater levels. Besides, Allen et al. (2004), Scibek and Allen (2006) also used numerical modeling to simulate groundwater levels in two aquifers in Canada and United States and found only minor impacts caused by climate change.

Stochastic models have also been widely applied in groundwater studies. Bekesi et al. (2009) applied trend analysis to model short, medium and long term groundwater decline and establish appropriate response management. Castellano-Mendez et al. (2004) presented an interesting application of two different modeling approaches, i.e., time series analysis and artificial neural networks (ANNs) in order to simulate and successfully forecast rainfall–runoff processes at different time scales. They concluded that Box–Jenkins models are a suitable method to study the long-term behavior of hydrological variables such as monthly rainfall or runoff. For short interval hydrological series however, they found that an ANN model provides more accurate results.

The aim of the present study is to develop a model for the prediction of groundwater levels, considering the effects of external parameters such as climate and human interventions and to investigate the complex interactions among various water bodies. The well known Box–Jenkins models were applied for time series analysis (Box and Jenkins, 1976), mainly in the form of a seasonal Auto-Regressive Integrated Moving Average (ARIMA) model. Applications of seasonal ARIMA models for prediction of environmental parameters can be found in literature. Chanbarpour et al. (2008), used an ARIMA model to study monthly baseflow time series in six different basins in southwest Iran, Ahn and Salas (1997) used ARIMA model to determine uniform sampling time of groundwater levels, whereas Adamowski and Hamory (1983) used an ARIMA model to study groundwater fluctuations in response to river flow changes. Juckem et al. (2008) used an ARIMA model in order to explain a step increase in baseflow and precipitation observed around 1970 in the Kickapoo River Watershed, located in the Driftless Area of Wisconsin.

In our work, two types of seasonal ARIMA models were developed for Neon Sidirochorion aquifer (also known as Sidirochori aquifer) in northern Greece (Fig. 1a) and were combined within a GIS environment in order to study the temporal and spatial behavior of groundwater level time series to external stresses. The first type of ARIMA model simulates the abstraction time series. In this case, temperature was found to be an important predictor variable and was incorporated as independent variable in the model. The second type of ARIMA models simulates the groundwater level time series and comprises eight individual ARIMA models, one for each of the eight monitoring locations. In each case the important predictor variables were determined and were incorporated in the model.

2. Materials and methods

2.1. Study area description

The study area is located in north eastern Greece and focuses on a semi confined aquifer known as Neon Sidirochorion aquifer formed in the alluvial plain of Vosvozis river (Fig. 1a).

It is located approximately 5 km from the Thracian sea and covers an area of approximately 35 km^2. The southern part of the

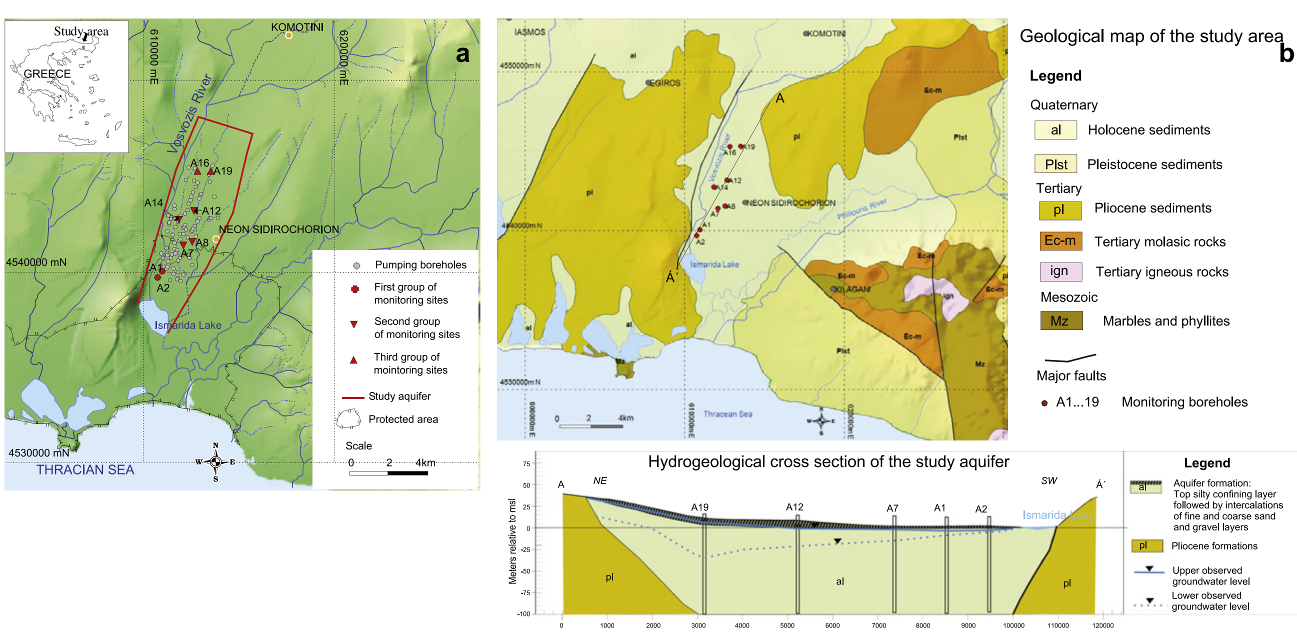

Fig. 1. (a) Location map of the study area with pumping boreholes and monitoring sites and (b) geological map and hydrogeological cross section of the study aquifer.