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The Karla Aquifer (Central Greek), an Agricultural Region under Intensive Environmental Pressure Due to Agricultural Activities. Agricultural Simulations under Climate Scenarios

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Abstract: The Agricultural Policy Environmental eXtender (APEX) model is used to study how different agricultural practices, such as fertilizing, irrigation, and tillage, would affect water quality and runoff in the Lake Karla watershed (Central Greece). The model was calibrated for the potential evapotranspiration with satisfactory results for the period 1980–2008 and for the yields of the main crops grown in the region (cotton, maize, wheat) for the period 1980–2015.

Keywords: Agronomic Simulation; APEX; Lake Karla watershed

1. Introduction

The challenges, which the agricultural sector must deal with are multidimensional and big. On the one hand, the increase in production is intended to cover the nutritional needs of the rapidly growing population. On the other hand, limiting the use of water, fertilizers, and pesticides to protect the sustainability of agroecosystems while protecting the natural environment from problems such as nutrient losses with nitrogen losses often used as a typical example. In recent years, the difficulties created by these challenges are aggravated by the projected climate change [1–4]. Scientists apply simulation models to examine all the aforementioned challenges [4]. Simulation models are an approach to represent quantitative knowledge about the system of interest and how the different components of that system interact. Agroecosystem models can help agronomists to understand crop grow, predict crop yields, and assess management for better water and nutrients use. Climate data, soil, and information about the management of the agroecosystem are used to inform these models. Such agroecosystem tools can normally simulate many periods, locations, managements, and scenarios and can provide in many ways useful information to agricultural science and farming, exploring the changing aspects between the atmosphere, the plant, the soil, and the water assisting in crop agronomy, pest management, plant breeding, natural resources management, and evaluating the effect of climate change [5]. In this article, we present the activities that are currently carried out for an ongoing project where the Agricultural Policy Environmental eXtender (APEX) model is applied in a rural region in Central Greece to assess crop production and water and nitrogen losses under current and future weather conditions.

2. Methodology

The APEX model has been implemented for the aquifer of the Karla Basin. APEX was developed to help evaluate different land management strategies in terms of their environmental impact, erosion, cost, and possible water supplies. APEX simulates the nitrogen and the water process, the crop yield, at the field, farm, or watershed level subdividing the simulated area in several units with homogeneous soil, weather, land use, and topography commonly defined subareas [6,7]. Karla watershed is an area with intense agricultural activity [8]. Figure 1 presents the land uses and crop classification for the Karla aquifer, as displayed within the ArcAPEX interface. After the delineation process, ArcAPEX separated the study area into 34 homogeneous subareas. The model was set to simulate 46 years in total with the first 10 years used as spin-up period and not considered in the calibration process. For the calibration, cumulative monthly data from 1961 to 2009 were used for the potential evapotranspiration (PET) while the crop yield of the main crops was calibrated considering the period 1980–2015.

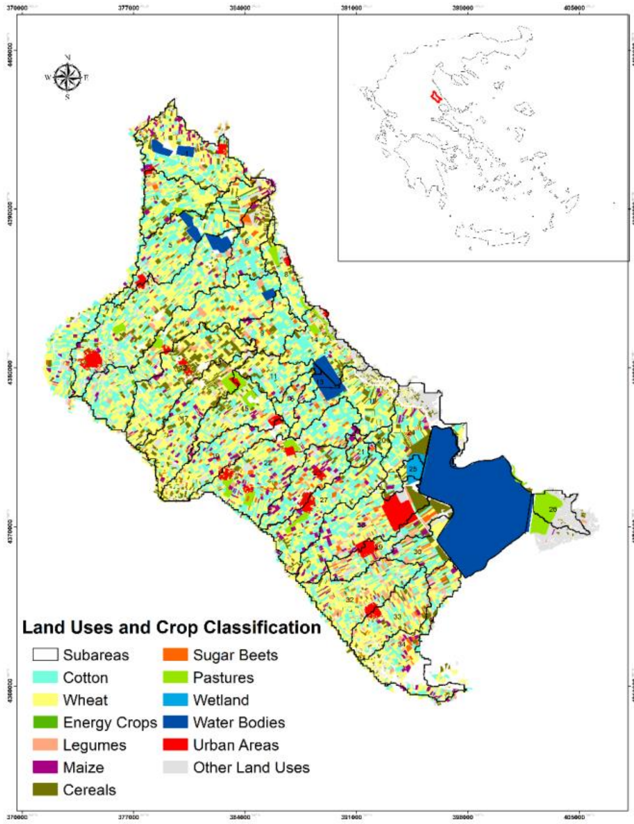

Figure 1. The study area.

Two statistical criteria were used to evaluate the results obtained for PET. The Nash–Sutcliffe Model Efficiency (Ef) in Equation (1) and The Coefficient of Determination (R^2) in Equation (2) indicate how well the model describes adaptation in the observed and estimated data.

$$Ef = 1 - \frac{\sum_{t=1}^{T}\left(Y_m^t - Y_O^t\right)^2}{\sum_{t=1}^{T}\left(Y_O^t - \overline{Y_O}\right)^2} \quad (1)$$

where $\overline{Y_O}$ is the mean observed value, Ym is the estimated value by the model and Yo is the observed at time t. Ef ranges from 1 (best result) to minus infinite.

$$R^2 = \left[\frac{\sum(x-\bar{x}) - (y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}}\right] \quad (2)$$

where x and y are the observed and the estimated values by the model, $\bar{x}$ and $\bar{y}$ are the mean observed and estimated values by the model, respectively. R^2 ranges from 1 (best results) to 0 (worst result).

3. Results

The APEX model was initially calibrated considering the PET. During the calibration process, four methods for the PET estimation were examined with the Hargreaves approach resulting as the best method. The results for Ef and R2 are presented in Table 1. Figure 2 shows the scatter plot where the observed and simulated values of PET are compared. As reported in Table 1, the model was able to provide a good estimate of PET resulting in a Ef value of 0.85 and R2 of 0.90

Table 1. Statistical Criteria Results.

Statistical Criteria	Results
E_f	0.85
R^2	0.90

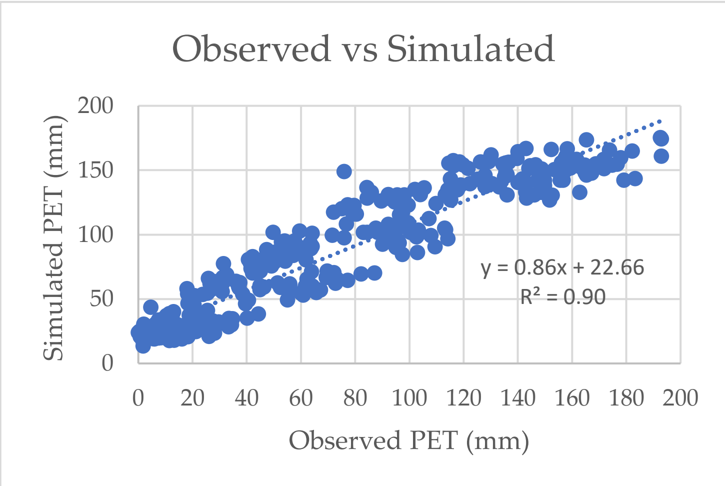

Figure 2. Comparison of the observed and simulated PET.

The work continued with the calibration of yields of the main crops grown in the study area (cotton, maize, winter wheat). It is worth noting that the calibration of crop yields was based on the average crop yield of winter wheat, cotton, and maize provided by the Greek Ministry of Rural Development and Food [9]. Due to the fact that APEX reports the yield as dry weight, the reported yield data has been adjusted for moisture content. We considered a moisture content between 6.5% to 8% for cotton [10], 14% for maize and wheat. After adjusting the average observed crop yield for the moisture content, the target crop yield for calibration where 2.6–3.2 Mg ha^{-1} for cotton, 8.6–17.2 Mg ha^{-1} for maize and 2.0–3.0 Mg ha^{-1} for wheat. Having only one average reported yield available, it was not possible to conduct a statistical assessment of the performance in simulating crop yield. Figures 3–5 show the simulated crop yield for all the simulated years after the calibration process for wheat, cotton, and maize respectively. The values reported are the average of the yield simulated by the APEX model in all the areas where each crop is cultivated within the watershed.

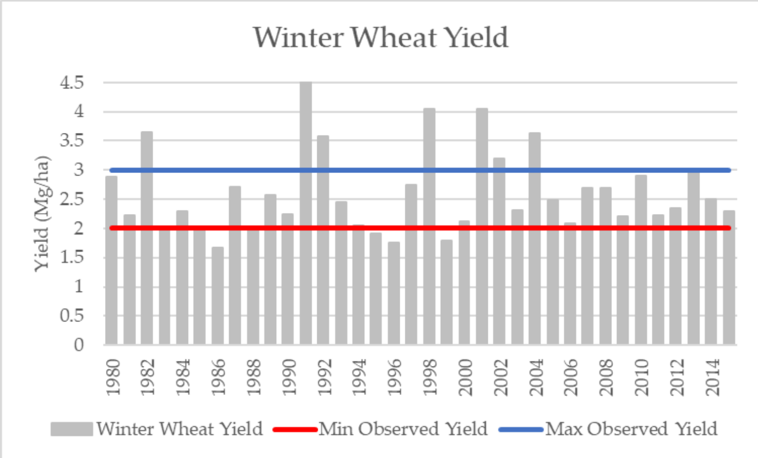

Figure 3. Simulated wheat yield, minimum and maximum average reported yield.

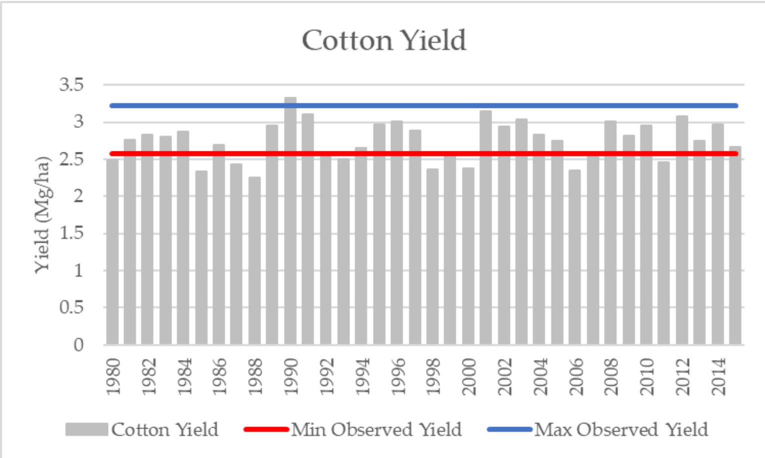

Figure 4. Simulated cotton yield, minimum and maximum average reported yield.

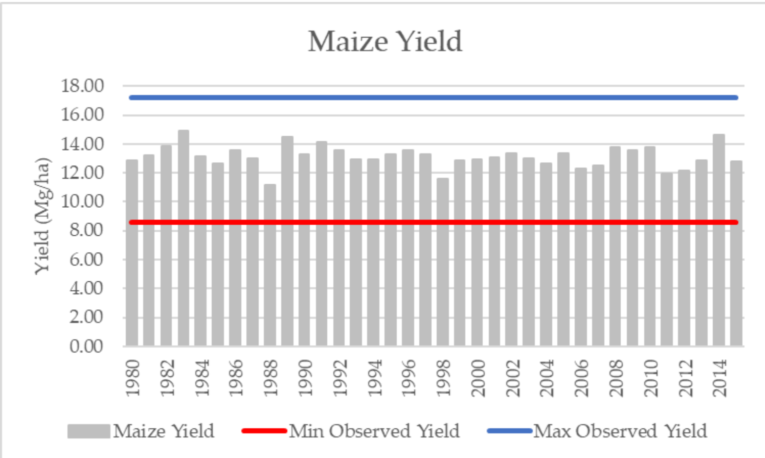

Figure 5. Simulated maize yield and minimum and maximum average re-ported yield.

After the calibration process, the model was able to provide good results in simulating crop yield. Average simulate yield for wheat was 2.6 Mg ha^{-1} which is in the rage of the average reported yield. In some years, the yield was overestimated probably because of an overestimation of the crop available water that, in turn, produced no water stress and very high crop yield. We will continue to analyse this aspect to improve the quality of the results for this crop. The average simulated yield for cotton was 2.75 Mg ha^{-1} which is within the range of the average reported yield with some years where the simulated yield is below the minimum or above the maximum average reported yield. Results for maize where better with an average simulated yield of 13.1 Mg ha^{-1} and yield within the reported range for all the years.

To calibrate the crop yields, parameters that regulates the simulation of soil water content (soil water lower limits and soil evaporation), and the effect of water stress and high temperature on the harvest index were adjusted. Also, the Harvest Index for maize was revised to consider the higher harvest index of the new maize hybrids obtained thanks to plant breeding and genetic improvement.

The calibration process will be continued considering the runoff and finally the nitrate leaching. In the final step, the APEX model will be used to study the impacts of climate change scenarios on the agro ecosystems of the Karla watershed.

4. Discussion

At the beginning of this activity, we were able to design within the APEX model the Karla watershed. The first step was based on the automatic delineation of the watershed using the ArcAPEX interface. After this initial step, the input files generated by the interface required some modification to better represent features of the watershed that was not correctly captured by the ArcAPEX interface such as the presence of a reservoir in the lower part of the watershed. After setting up all the input data required by the model, we started the calibration procedure. Beginning with the calibration of the PET, which we consider as the starting point to have a good simulation of the water balance, we were able to obtain good results with R^2 of 0.9 and Ef of 0.85. The good results obtained for the PET are followed by satisfactory results in the simulation of yield of the three main crops cultivated in the studied area. The APEX model was able to produce reasonable results for the yield of maize, cotton, and wheat with some overestimation that require some analysis for the later crop. When the calibration process will be completed by including the analysis of runoff and nitrate leaching, the model will be used to assess how climate change will affect crop production and water and nutrient losses..

5. Conclusions

This modeling study will allow us to better understand if the APEX model could be considered a useful tool to study agroecosystems in the Mediterranean climate. Obtaining good results in the calibration and validation process will allow us to use the APEX model to assess the impact of land management and climate change in the Karla watershed.

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Conflicts of Interest: The authors declare no conflict of interest.

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