Agricultural Water Management 161 (2015) 86–101

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Climate change impact on water resources and crop production in Armenia

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ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form 7 July 2015
Accepted 8 July 2015

Keywords:
Water resources
Irrigation
Crop management
Climatic and meteorological parameters
Vulnerability

ABSTRACT

Agricultural sector of small, mountainous country Armenia is very vulnerable towards climate change, due to frequent drought episodes, enhanced air temperature, reduced precipitation, increased evaporation rates and water scarcity. To maximize the crop production in a country with specific economic structure, where 21% of GDP is formed in the agricultural sector, it is necessary to estimate the capacity of agrometeorological and water resources, effectiveness of irrigation amounts under the current and future climate conditions, which is the main aim of the given study.

Armenian State Hydrometeorological Service provided the data on meteorology (air temperature, precipitation, relative humidity, wind speed and direction) for 30 stations distributed evenly over the whole territory of the republic during the time period of 1966–2010. For interpolation of climate variables within the region, climate of the South Caucasus has been modeled firstly for the current situation with the mesoscale METRAS model (Mesoscale Transport and Stream) with 12 km spatial resolution. Later on, based on General Circulation Models (GCMs) climate projections for the near future (until 2040) have been realized showing significant increase in average air temperature by 1.6 K, but no reliable changes in precipitation sum; still dryness is obvious in the region.

Further agrometeorological parameters (potential and actual evapotranspiration, soil temperature and humidity) have been assessed applying AMBAV model (Agrarmeteorologisches Modell zur Berechnung der aktuellen Verdunstung) developed by German Weather Service in Braunschweig. The analysis showed that there is a significant difference in meteorological and hence, also in drought conditions (large differences in soil temperature and humidity, as well as the evapotranspiration sums) among dry and hot western states and relatively cold and humid northern states, which has a direct influence on potential and actual yield ratio.

Further the results of the model have been used in order to assess crop water irrigation requirements in the country utilizing crop development coefficients for various crop types at different growing stages in order to organize water management and irrigation systems efficiently. It was estimated that for each hectare 3000 m^3 water is required in current climate conditions, which will be nearly doubled in future in regard to climate change. This irrigation assessment for the entire country has been carried out for the first time allowing not only the farmers, but also the government to meet the new millennium challenges under climate change convention.

1. Introduction

Developing countries with agriculture as a dominant sector in economy and with limited water resources are very vulnerable towards climate change. Given the fact that the crop production process is very complex, it cannot be analyzed by applying only classical meteorological data because the important agricultural issues such as effective irrigation sums and timing, sowing and harvesting periods, forecast of the crop production for the next year or adaptation mechanisms, cannot be answered. Here the limiting factor is the absence of continuous measurements of soil temperature and humidity at different depths, water content at field capacity, permanent wilting point, snow coverage, potential and actual evapotranspiration, stomata and stand resistance, leaf area index. To assess these parameters AMBAV model (Agrarmeteorologisches Modell zur Berechnung der aktuellen Verdunstung) developed by German Weather Service in Braunschweig (Löpmeier,

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http://dx.doi.org/10.1016/j.agwat.2015.07.004
0378-3774/

1994) is applied. For investigating irrigation and water requirements, potential and actual evapotranspiration, as well as drought conditions should also be analyzed. Therefore, various drought indices have been assessed.

Keeping in mind the fact that the information required for effective farming is very limited to a small area covered by the measurements, climate modeling is required in order not only to provide all the necessary parameters for a broad crop production (on all the mountainous slopes), but also it would give an opportunity to forecast the climate in future managing the resources efficiently. For this reason, mesoscale non-hydrostatic model METRAS (University of Hamburg) has been applied during the vegetative period (April–October) having validated it with the measured data in advance. The model gave an opportunity to represent the climate (air temperature, precipitation) in the whole territory applying land use and topographic data of the South Caucasus region with 12 km spatial resolution. Further, application of this model can be used to downscale general circulation models for this area in order to obtain climate change in finer spatial resolution. This will give necessary information both to the farmers to organize the effective cultivation program (sowing dates, irrigation sums and timing) and to the government to plan the budget in accordance to agricultural production (possible subsidies for water resources or covering the loss due to drought conditions, arranging adaptation mechanisms at larger scales).

Having firstly examined the climate pattern in the research area (both measurements and model simulations of classical and agrometeorological parameters), practical calculations for crop water and irrigation requirements have been done using FAO methods. Later on this comprehensive analysis has been carried out for the whole territory of Armenia, hence representing an overall practical picture for farmers and decision makers to use the agricultural resources of the country in an effective way.

2. Theoretical background

To study the magnitude of the sensitivity, it is necessary to discuss the impact of various parameters on crop production as different authors differentiate various types of impact factors on agricultural production. These impact factors are distinguished in two major groups – external and internal (Zhou, 2012; Anwar et al., 2013; Liu et al., 2013). Internal factors include parameters such as social systems and policy, markets and industrialization, cultivation, irrigation systems, as well as fertilizing. Whereas the internal factors are subject of local controls, regulation norms and decisions of country government, the external factors consisting of mainly climate cannot be controlled to a high extent due to their random and sometimes unforeseeable character. Within the frames of this study both external and internal factors will be analyzed and modeled in order not only to realize a comprehensive analysis of crop production but also to be able to project it in the future climate.

This study is concentrated merely on grain production, given the fact that cereals are the most important crop type in the world economy accounting for more than 40% of human calorie intake and about 650×10^6 ha or 45% of global cultivated crop land (Teixeira et al., 2013). Nearly one sixth of total arable land in the world is under wheat cultivation (Rezaie and Bannayan, 2012). The highest share of the actual rain-fed cultivated area for wheat production is in Russia and the USA, but climatically suitable areas include also some south American and African countries as well (Osborne et al., 2013).

Using ensemble of widely used GCMs it is estimated that global cereal production will decrease in average by 33% if no adaptation in agricultural sector is taken and by 17% if adaptation, like altered sow and variety switch, are carried out in the world (Osborne et al., 2013). The decrease of cereal production is explained by a change in current cultivated area (Bouma et al., 1998), leading to an increase in cereal imports by 10–40% by 2080 especially in developing countries (Rosengrant et al., 2008). Using SRES (Special Report on Emission Scenarios) A2 scenario Schmidhuber and Tubiello (2007) estimated that cereal prices will increase even by 170% by 2080. Increased cereal imports together with increased prices in developing countries will threaten global food security.

To increase the yield production it is necessary to analyze the efficiency of agricultural factors, like irrigation and nutrients, for the given location. This might be achieved through studying the yield gap which is the difference of the potential yield (crop yield achieved with the optimal water and nutrients level) and the actual yield (average yield at the location, where 94% of cropland is under rain-fed) (Liu, 2012; Osborne et al., 2013). Yield gap, i.e., the ratio between potential yield and the actual yield, is further analyzed in dependence on water availability called as crop water production function (Geerts and Raes, 2009) defining water availability as the ratio between actual evapotranspiration and the crop water requirement (CWR). The latter represents total amount of water necessary to avoid water stress or to compensate the evaporation rate. The amount of water that must be applied in addition to precipitation to meet crop's evapotranspiration needs is given with irrigation requirement (IR). Apart CWR and IR, potential yield can be calculated according to the sum of annual rainfall. In this case available water is equivalent of 30% rainfall received between January and March plus 100% of rainfall during the growing season (April–October), with losses estimated at 30% of April–October rainfall. It is assumed that every millimeter of available water will produce 20 kg of wheat per hectare (French and Schultz, 1984). If supplied water is insufficient during the crop production period, the crop will not develop fully resulting to the high loss of yield. Yield increases with increased water levels, once a minimum amount of water is applied. With additional water, the production function becomes almost linear. In contrast, as soon as the ratio between actual and potential evapotranspiration approximates unity, the slope of crop water function decreases. When excess irrigation or rainfall is included, the crop production function gets then S-form, which indicates that applying more water than required, the yield will not increase any more, as the water is then lost through unproductive soil evaporation and/or deep percolation (Geerts and Raes, 2009). Taking only the ratio between actual yield and actual evapotranspiration (water productivity), crops with high water productivity should be preferred especially in dry regions. This analysis gives an important overview for the efficiency of using the water resources in semi-arid areas.

Besides the water resources, other important factors leading to the yield gap are insufficient sum of nutrients, pests, weed and diseases, as well as the poor mechanization and the lack of adequate knowledge (Hengsdijk and Langeveld, 2009; Zhou, 2012; Anwar et al., 2013). Therefore, to support food safety and sustainable agricultural research, the private sector spent 600×10^6 USD (56 percent in food manufacturing and 44 percent in agricultural input sectors) and accounted for about half of total public and private spending on food and agricultural R&D (Research and Development) in high-income countries in 2007 (Fuglie et al., 2011; Zhou, 2012). The most rapid growth in investments was for crop seed and biotechnology over the time period of 1994–2010. Investments in crop seed and biotechnology are mainly carried out in order to develop new kinds of seeds which will be more adapted to the future climate conditions. These genetically modified (GM) seeds being altered to improve growth or nutritional value, are widely spread especially in the USA (68×10^6 hectares are under the cultivation for biotech crops), followed by Argentina (25×10^6 ha) and Brazil (22×10^6 ha) (Mannion and Moerse, 2012). Whereas, implementation of GM seeds is one of the most important