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Environmental and socio-economic vulnerability of agricultural sector in Armenia

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HIGHLIGHTS

- Crop production has been analyzed in dependence on climatic parameters.
- Drought events have been investigated using drought indices.
- Agroclimatic resources have been assessed using an AMBAV model.
- Vulnerability analysis was carried out with the help of macroeconomic model.
- Crop production vulnerability was assessed in the current and future climate.

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ABSTRACT

Being a mountainous country, Armenia has undergone different kinds of natural disasters, such as droughts, floods, and storms, which have a direct influence on economy and are expected to occur more frequently in terms of climate change, raising the need to estimate economic vulnerability especially in agricultural sector. Agriculture plays a great role in national economy of Armenia, with 21% share in Gross Domestic Production (GDP). For this reason, the estimation of agricultural resources of the country, their vulnerability towards current and future climate, and assessment of economical loss of the agricultural crop production due to climate change are the main goals of the given study. Crop productivity in dependence on climatic elements — temperature, radiation, precipitation, wind field, etc. has been estimated, further on interpolating these relations for future climate conditions using climate projections in the region for the time period of 2011–2040.
Data on air temperature, precipitation, relative humidity, wind speed and direction for the period of 1966–2011 have been taken from 30 stations from the measuring network of Armenian State Hydrometeorological Service. Other climatic parameters like potential and actual evapotranspiration, soil temperature and humidity, field capacity, and wilting point have been calculated with the help of an AMBAV/AMBETTI (agroclimatic) model (German Weather Service).
The results showed that temperature increase accompanied with evapotranspiration increase and water availability decrease especially in low and mid-low altitudes (where the main national crop production is centralized) caused a significant shift in the phenological phases of crops, which is very important information for effective farming dates, giving an opportunity to raise efficiency of agricultural production through minimizing the yield loss due to unfavorable climatic conditions. With the help of macroeconomical analysis of the crop market, it was estimated that the economical loss of the wheat production due to even drier conditions in the future climate (2011–2040) will be more than doubled, causing essential problems in irrigation systems with sparse water resources.

1. Introduction

The crop production process is very complex and cannot be described with only classical meteorological data (air temperature, precipitation, etc. measured in the network of the National Hydrometeorological Service). Even though most of crop production variance can be explained by the classical meteorological parameters, important agricultural issues like sowing and harvesting periods, forecast of the crop production for the next year or adaptation mechanisms, like coverage and burial of crop during winter period (against freezing) can't be answered. Here the limiting factor is the absence of continuous measurements of crucially important parameters like soil temperature and

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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 (Bannayan et al., 2011a, b) especially in developing countries. Holzkämper et al. (2011) defined crop development being dependent on average solar radiation, average minimum and maximum temperature, water balance (precipitation–evapotranspiration), phase length, and number of heat or frost days. The potential of all these hydrometeorological elements influencing the efficiency of crop production is called agroclimatic resources (Agroclimatic Resources of Armenia, 2011b). Different models calculate these parameters. Hattermann et al. (2011) used SWIM (Soil and Water Integrated model), getting as output not only the above mentioned parameters, but also river runoff (Elba basin, GLOWA project).

Within the frames of the given study the AMBAV/AMBETI model ('*A*grarmeteorologisches *M*odell zur *B*erechnung der *a*ktuellen *V*erdunstung') developed by German Weather Service in Braunschweig (Löpmeier, 1994) is applied to model the agroclimatic resources of Armenia. Input data on classical meteorology were taken from the measuring network of Armenian Hydrometeorological Service (ASHMS, 2011) and data on radiation budget were received from Satellite data (German Aerospace Centre; CM SAF, 2013). Permanent wilting point, field capacity, soil temperature in 5 and 10 cm depths, actual and potential evapotranspiration, and LAI (leaf area index) are received as output. These parameters are vitally important to examine the crop production. When water is accumulated and it becomes equal to field capacity (FC), this point is the onset of the plant or crop growing season or vegetative period length (Bannayan et al., 2011a). Generally this is the period, when the mean temperature is above 10 °C (Alexandrov and Hoogenboom, 2000). To complete the annual cycle (vegetative period) each crop needs specific amount of heat, that is the sum of daily average temperature accumulated from the beginning of vegetation until the end of maturity.

To generalize the dependence of crop sensitivity on meteorology, and analyze crop production in an arid region of Armenia, drought indices are used in this study (Standardized Precipitation Index (SPI), Selyaninov hydrothermal ratio and heat stress index), using the data of only temperature and precipitation, considering the fact that climate projections give reliable information only on these parameters for the future climate.

As a summary, the main aim of the given research is to evaluate agroclimatic resources of Armenia and their influence on agronomic production (winter wheat is considered here) and finding out the potential of raising crop production efficiency for a developing country (Armenia) with specific economic structure and climatic characteristics. These interrelations between climate and harvest enable to develop effective crop management programs in dependence on climate change projections protecting the economy from large GDP losses. The GDP losses due to drought events and water shortages have been evaluated and modeled for the future having used the macroeconomic model evaluating demand and supply of winter wheat in dependence on climatic parameters (Melkonyan and Asadoorian, 2013).

2. Theoretical background

Grain production is the most important in the world economy — nearly 1/6th of total arable land in the world is under wheat cultivation (Rezai and Bannayan, 2012), though cereal production in developing countries decreases by 5%. It is estimated that cereal imports will increase in developing countries by 10 to 40% by 2080 (Rosengrant et al., 2008). Using SRES A2 scenario Schmidhuber and Tubiello (2007) estimated that cereal prices will increase even by 170% by 2080 rescuing global food security. FAO defines food security as a 'situation that exists when all people at all times have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life'. Full trade liberalization in agriculture would provide more efficient resource use and would lead to higher value added in agriculture globally supporting poverty reduction (Parry, 2007).

Keeping in mind the fact that climate plays a great role in agricultural production especially in the countries with transient economies and areas with complex topography, the issue to investigate efficiency of crop production in dependence on meteorological parameters arises, which generally is carried out with the help of multiple regression analysis. For instance, Alexandrov and Hoogenboom (2000) applied regression analysis, where crop production was taken as a dependent variable, temperature and precipitation (in March, July, August) as independent variables, further on developing a genetic grain cereal model (CERES), which calculates crop phase and morphological development as a function of temperature, daylight length and genetic characteristics. Application of this methodology (multiple regression analysis) is very important to project the crop production in the future under climate change. According to the climate projections carried out with four global circulation models — ACCESS (The Australian Community Climate and Earth System Simulator), MPIM (Max Plank Institute Model), CNRM (Centre National de Recherches Meteorologiques), and GFDL (Geophysical Fluid Dynamic Laboratory) for two scenarios (RCP 4.5 and 8.5 — radiation increase by 4.5 and 8.5 W/m^2) during three periods 2011–2040; 2041–2070; and 2071–2100, the country will have by 1.3 K (RCP 4.5) and 1.6 K (RCP 8.5), by 2.1 K (RCP 4.5) and 3.6 K (RCP 8.5), and by 3.0 K (RCP 4.5) and 6.0 K (RCP 8.5) higher temperatures, respectively for each period. But to monitor the temperature increase and its impact on crop production in the future, it is useful to investigate the temperature changes in the past on the basis of the long-term data, which has been carried out in this study.

Because of rapid increase in temperatures during the last four decades, the growing season has also been altered. The analysis of crop growth length is an important adaptation measure in water management through changing the planting date towards a less risky period or getting a possibility for the second harvest (Alexandrov and Hoogenboom, 2000; Bannayan et al., 2011b).

Reduction of precipitation by 6% has been reported during the last 80 years. The highest decrease was observed at the highest (2.41 mm/year) and the lowest (1.13 mm/year) altitude. The number of dry days (daily sum of precipitation is smaller than 1 mm) increased by 0.4 day per year in the region of Ararat (western state of Armenia), where the agricultural production is centralized (ASHMS, 2011).

The analysis of hydro-meteorological hazards including droughts, floods, heavy rains, and storms, showed that on average every day some hazardous events occurred in the territory during the period of 1975–2006. The highest number of days with hydro-meteorological hazards is recorded in 2003 and 2004 (ANRS, 2011a). Nevertheless, the most important natural disaster for Armenia is drought, towards which the whole territory of Armenia is highly vulnerable. Nearly 50% of the cultivated area is under irrigation. While irrigated areas are impacted by the severity of drought in varying degrees, the rainfed areas are directly affected by drought (Lazar et al., 1995; Rezai and Bannayan, 2012). The severe drought in 2000 resulted in a loss of 2.7% of the whole GDP and 10.1% loss in agricultural GDP. The total loss was estimated to be USD 57 million. Drought increases vulnerability towards other natural hazards, e.g. loss of soil moisture exacerbates the intensity of mudslides and spread of pests (Source; World Bank, "Drought: Management and Mitigation Assessment for Central Asia and the Caucasus", 2005).

During the drought episodes decreased water availability due to erratic rainfall and growing demand among all users of water is expected to reduce the availability of water for agriculture. To study drought events, there are a couple of drought indices used worldwide, such as Palmer index, Standardized Precipitation Index (SPI), Crop moisture index, Surface water supply index, and Selyaninov hydrothermal ratio (Guttman, 1998; Agnew, 2000; Heim, 2002; Breustedt et al., 2008; Leblois and Quirion, 2013). Some of these indices require a huge set of input data, which is very limited in Armenia. For this reason, SPI and