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Prediction of Climatic Change for the Next 100 Years in the Apulia Region, Southern Italy

Burcak Kapur*[1], Pasquale Steduto[2], Mladen Todorovic[3]

[1]Çukurova University, Agricultural Faculty, Department of Agricultural Structures and Irrigation
01330 Adana, Turkey
[2]Head of Water Resources, Development and Management Service Land and Water
Development Division Agricultural Department of FAO
[3]Istituto Agronomico Mediterraneo
Via Ceglie 9, 70010 Valenzano (BA), Italy

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Abstract

The impact of climate change on water resources and use for agricultural production has become a critical question for sustainability. Our objective was investigate the impact of the expected climate changes for the next 100 years on the water balance variations, climatic classifications, and crop water requirements in the Apulia region (Southern Italy). The results indicated that an increase of temperature, in the range between 1.3 and 2,5 °C, is expected in the next 100 years. The reference evapotranspiration (ETo) variations would follow a similar trend; as averaged over the whole region, the ETo increase would be about 15.4%. The precipitation will not change significantly on yearly basis although a slight decrease in summer months and a slight increase during the winter season are foreseen. The climatic water deficit (CWD) is largely caused by ETo increase, and it would increase over the whole Apulia region in average for more than 200 mm. According to Thornthwaite and Mather climate classification, the moisture index will decrease in the future, with decreasing of humid areas and increasing of aridity zones. The net irrigation requirements (NIR), calculated for ten major crops in the Apulia region, would increase significantly in the future. By the end of the 21st Century, the foreseen increase of NIR, in respect to actual situation, is the greatest for olive tree (65%), wheat (61%), grapevine (49%), and citrus (48%) and it is slightly lower for maize (35%), sorghum (34%), sunflower (33%), tomato (31%), and winter and spring sugar beet (both 27%).

Key-words: climate change, water balance, irrigation requirements, Apulia.

1. Introduction

Climate, through its major attributes or "variables" (temperature, precipitation, wind, etc.), exerts a strong influence on physical and biological aspects of the global natural environment. It affects the types of soils, vegetation including animal life, and human activities as well (e.g., agriculture, buildings, tourism, transportation, etc.). Because the different natural (cosmic, tectonic, oceanic, volcanic, etc.) and anthropogenic influences (land use, atmospheric pollution, etc.) climate changes with time. Thus, "climate change can be regarded as a variation from the 'expected' climatic condition" (Maunder, 1995).

Recent concerns about climate change have focused on mankind's enhancement of the natural "change" through atmospheric pollution (mainly greenhouse gases), that modifies the composition of the atmosphere, which in turn "changes" the energy balance of the globe and pushes the resulting climate toward an expected "global warming". In order to identify anthropogenic influences, changes in climate need to be placed in the context of much longer-time changes in climate that have taken place naturally in the past. Only direct records of the climatic elements provide an adequate perspective on climatic change, now and in the future. A longer-term perspective on climate variability can be obtained from the study of natural phenomena which are climate-dependent.

* Corresponding Author: Tel.: +90 322 3386510; Fax: +90 322 3386380. E-mail address: ozekici@cu.edu.tv

Over the past century, the Earth's surface and lowest part of the atmosphere have warmed up on average by about 0.5 °C (Jones et al., 1999). During this period, the amount of greenhouse gases in the atmosphere has increased, largely as a result of the burning of fossil fuels for energy, transportation, and agriculture. Global warming is now considered to be the man-made increases in greenhouse-gas emissions (Hansen et al., 1998). Other natural causes of climate change include changes in the amount of energy coming from the sun and shifting patterns of ocean circulation. These evidences clearly indicate that there is a discernible human influence on the global climate (Crowley, 2000).

The warming trend is expected to continue in the near future (about 2.5 °C within the next 100 years) and with a strong concern on the impact that such change will have on the earth's ecosystems and human life, in different regions of the world. Patterns of agriculture, industry, human health and settlements, the natural environment, and land and water resources are all experiencing the effects of the expected climate change. Numerous studies have been and currently are underway to investigate the possible consequences and to devise measures to counteract the predicted undesirable outcomes (IPCC, 2001).

At the most general level there is wide agreement that the impacts will be diverse. Some effects may be beneficial, while other effects may be counteracted through minimal adaptation. For the majority of people, however, the consequences of climate change will probably be negative and for some regions they could be disastrous. Accordingly studies of climate change and it's affects on future crop water requirements, relevant to the subject of this paper, bear utmost significance in determining, primarily the future of agriculture and it's countrywide policies. These policies will, most probably, contribute to the ultimate goal seeking to attain sustainability in the future climate and/or adaptability to future changes.

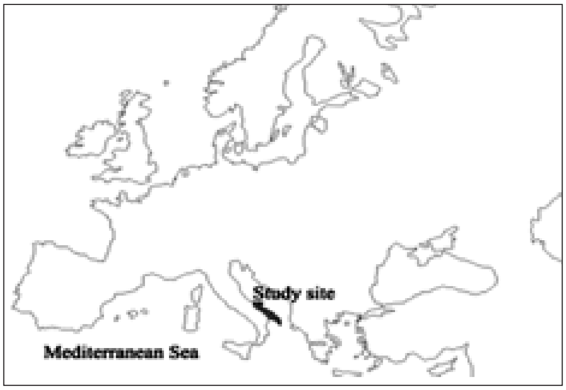

Figure 1. Location of study area.

2. Materials and methods

The investigations reported here on the climate change and climatic water balance were carried out in the Apulia region, southern Italy (Fig. 1). The projected climatic change data for the period 1950-2100 were supplied by the UK Hadley Center for Climate change (estimated by HadCM3, a coupled atmosphere-ocean general circulation model developed by Hadley Centre for Climate Prediction and Research (UK), while the initial set of historical weather data for 162 locations within the study area was taken from the Italian National Hydrographic Institute. Several methods for data processing, including spatial interpolation techniques, climate classifications, estimation of climatic water deficit and irrigation requirements were applied in this work.

Monthly temperature and precipitation data measured at the 162 meteorological stations over a period of 40 years (1950-1990) formed the initial database, which was later extended to include the period 1990-2100 on the basis of the expected climate changes estimated by HadCM3. The downscaling from global to regional scale was performed on monthly data averaged on a 10-years basis.

For both the array of meteorological stations and the grid cells of the HadCM3 model, reference evapotranspiration (ETo) was estimated by the Hargreaves method (Hargreaves and Samani, 1985) since the input data set includes only Tmax and Tmin. The reference evapotranspiration was calculated on a monthly basis. Previous investigations in the region have demonstrated that the use of the Hargreaves method yields more realistic values than the Blaney-Criddle method.

The Hargreaves method is a simple empirical equation which uses the values of extraterrestrial radiation (R_a) as an input, in addition to the minimum and maximum air temperatures (T_{min} and T_{max}, respectively). The following form of the Hargreaves equation was applied:

$$ET_o = 0.0023\frac{R_a}{\lambda}(T+17.8)(T_{max}-T_{min})^{0.5} \qquad (1)$$

where λ is the latent heat of vaporization. T is an average temperature in °C, calculated as:

$$T = \frac{T_{min}+T_{max}}{2} \qquad (2)$$

and where the multiplier (0.0023), the exponent (0.5), and the value of 17.8 in the third multiplier of the equation, are constant values determined empirically.

The Climatic Water Deficit then could be calculated on monthly basis as a difference between reference evapotranspiration (ETo) and precipitation (P):

$$CWD = ET_o - P \qquad (3)$$

The *Net Irrigation Requirements* (NIR) were then calculated on a monthly basis for ten selected crops, widely cultivated in the Apulia Region, namely: citrus fruits, olives, grapes, winter sugar beet, spring sugar beet, wheat, sun-flower, maize, tomato and sorghum.

The *Crop Water Requirements* were calculated through a two step approach:

$$ETc = ETo * Kc \qquad (4)$$

ETc = standard crop evapotranspiration (mm/day)
Kc = crop coefficient (dimensionless)
ETo = reference evapotranspiration (mm/day)

The Kc values used were derived from experimental work carried out by the University of Bari.

The *Effective rainfall* was calculated for the whole area from:

$$Peff = P * 0.8 \qquad (5)$$

Finally the NIR is calculated for every month during the growing seasons as

$$NIR = ETc - Peff \qquad (6)$$

In the analysis, the Kc values at the beginning and the end of the growing season were assumed to remain constant for the next 100 years.

The method of Thornthwaite and Mather (1957) was applied for the climate classification of the Apulia region. Thornthwaite and Mather (1957) introduced the most relevant humidity (and aridity) index that involves a comparison of the amount of water added to a particular climatic region (P) not with average temperature (T), but directly with the existing or potential water content of that climatic region. This approach represented a major evolutionary step in climatic classification and required the introduction of a new climatic element, i.e., the potential evapotranspiration (ETP), representing the evaporative demand of the atmosphere, and here termed the reference evapotranpiration (ETo).

Once the ETo is determined, two basic variables can be derived: 1. The *deficit* (d) when P < ETo, and 2. The *excess* (w) when P > ETo. Then, the aridity (Id) and the humidity (Iw) indices of Thornthwaite can be defined as:

$$Id = \frac{d}{ETo}*100 \quad \text{and} \quad Iw = \frac{w}{ETo}*100 \qquad (7a, 7b)$$

Subsequently, Thornthwaite and Mather (1957) combined these two indices within a global moisture index (*Im*) calculated from:

$$\mathrm{Im} = \frac{P - ETo}{ETo}*100 \qquad (8)$$

The index *Im* is positive for humid climates (w > d) and negative for arid climates (w < d). This index is a critical component in the climatic classification of Thornthwaite and Mather (1957), where it is linked to other expressions.

The global moisture index *Im* thus provides a valuable measure of the aridity or humidity of a given region, the major climatic classes defined by Thornthwaite and Mather (1957) being based on his moisture index (Tab. 1).

Table 1. Major climatic classes according to the moisture index of Thornthwaite and Mather (1957).

Climatic Classes	Climatic Description	I_m range
A	hyperhumid	> 100
B_4	humid	80-100
B_3	humid	60-80
B_2	humid	40-60
B_1	humid	20-40
C_2	humid/subhumid	0-20
C_1	subhumid/subarid	-33.3-0
D	semiarid	-66- -33.3
E	arid	-100- -66.6

Table 2. The Thermal efficiency symbols and descriptions, according to the Thornthwaite and Mather (1957) classification.

Symbol	ETo ranges (mm)	Climatic Group
A’	> 1440	Megathermic
B_4’	1440-997	Fourth mesothermic
B_3’	997-855	Third mesothermic
B_2’	855-712	Second mesothermic
B_1’	712-570	First mesothermic
C_2’	570-427	Second microthermic
C_1’	427-285	First microthermic
D’	285-142	Tundra
E’	< 142	Frost

In addition to this aridity/humidity grouping, it is also necessary to consider the average temperature and how this may be grouped. For this aspect, Thornthwaite concentrates on the thermal requirement of vegetation, thus introducing the thermal efficiency index as a function of the annual ETo which, in turn, is an expression of the water requirements for plant growth. (In one sense, ET is linked to T, and then T is linked to growth). The additional notation to identify climatic groups thermally, making use of the thermal efficiency index, is given in Table 2.

3. Results and discussion

An overall increase of global temperature, in the range between 1.3 and 2.5 °C, is expected over the next 100 years within the Apulia region, the area of land experiencing average annual temperatures ranging between 15 and 17 °C would decline from the current value of more than 60% to less than 10% by the end of the present Century. An increase of the area with the temperature range of 17-19 °C is foreseen, from a few percent (present situation) to more than 60% (for the decade 2090-2100). Those areas with an average annual temperature in the range of 13-15 °C will almost completely disappear (from 30% at present to 4% in 2091-2100) and the areas with temperature between 19 and 21 °C will increase from less than 1% in the middle of the 21st century to almost 20% by the end of Century. Figure 2 represents the variation of temperature in the region depending on areal basis. The results are similar to the projected percentage changes of temperature in the Edwards Aquifer region of

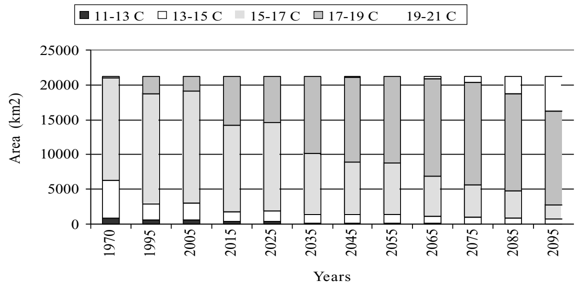

Figure 2. Histogram representing the variation of temperature in the region.

Texas, where the Hadley Centre for Climate Prediction and Research predicts an increase in temperature of about 9% over the next 100 years (Chen et al., 2001). The foreseen temperature changes in our study area for the same period fall within the same range, as also in a study conducted in Israel where mean temperatures are predicted to increase between 1.6 to 1.8 °C over the next 100 years (Pe’er and Uriel, 2000).

The ETo variations follow a similar trend to those forecast for temperature. In fact, when averaged over the whole region, the foreseen increase of ETo would be about 15.5%. An enhanced ETo is foreseen for almost every month, with the peaks observed in June and July of more than 25 mm/months. These results demonstrate that at present most of the Apulia region (between 70 and 80%) lies within the range 1000-1200 mm but the surface area displaying this Eto range will probably decrease. Moreover, it is expected that the small area presently characterized by ETo values between 900 and 1000mm will completely disappear, while a strong expansion of the areas with Eto values in the range 1200-1300mm is foreseen, especially in the second part of the 21st century. In some other investigations, researchers have predicted that the potential evapotranspiration may increase by 30% by the year 2100 (for example in central Poland: IUCC, 1994), whereas this study indicates that over the next century the evapotranspiration may increase by 35%. A study of Southern Africa, utilising published model scenarios for 2050 and following standard IPCC methodology, reported that evapotranspiration may increase between 5% and 10% over the next 50 years (Sherman, 1992), whereas in this study, evapotranspiration in Apulia is foreseen to increase by 4% by 2050. According to Pe'er and Uriel (2000) the overall temperature increase of 1.5 °C in the Mediterranean basin, anticipated in Israel around 2100, which is expected to enhance evapotranspiration rates by 10% (Jeftic, 1993). In the present study, over the next century the temperature is predicted to increase by 2 °C and evapotranspiration is enhanced by up to 11%.

The anticipated climatic water deficit (CWD) increase is largely caused by these enhanced ETo values and over the next 100 years CWD in the Apulia region is calculated to increase on average for more than 200mm (Fig. 3). This trend is most marked for the period 2060-2100, when the water deficit is predicted to fall in the range of 600-800 mm over most of the region, while in the last decade (2090-2100) in some areas the CWD would increase to 905 mm. Over the next century, the areas with CWD in the range 600-800 mm are expected to increase from only a few percent to more than 50%. The total surface area with water deficits between 300 and 500 mm will also decline from the present value of 65% to 15% by the end of the 21st Century (Fig. 4). Moreover, by that date,

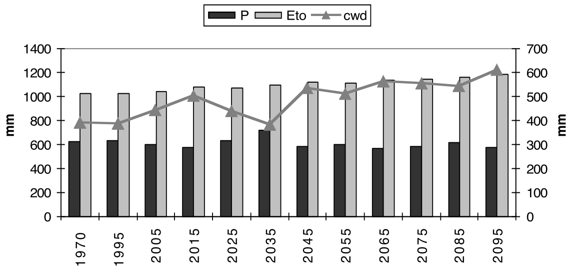

Figure 3. Average variation of precipitation (P), ETo and CWD (Climate Water Deficit) in the Apulia region for the period 1950-2100.

it is expected that the total area displaying water deficit values greater than 800 mm will represent about 10% of the study region. Some other investigations of the effects of climate change (e.g. GEO, 2000) have reported results indicating that in the Arabian Peninsula, for example, the annual climate water deficit could increase to 67% of the actual demand by 2015. Nevertheless, from our study, the climate water deficit of the entire Apulia territory in the same period may increase by 30%.

The moisture index will decrease in the future, resulting in a decrease in areas classified

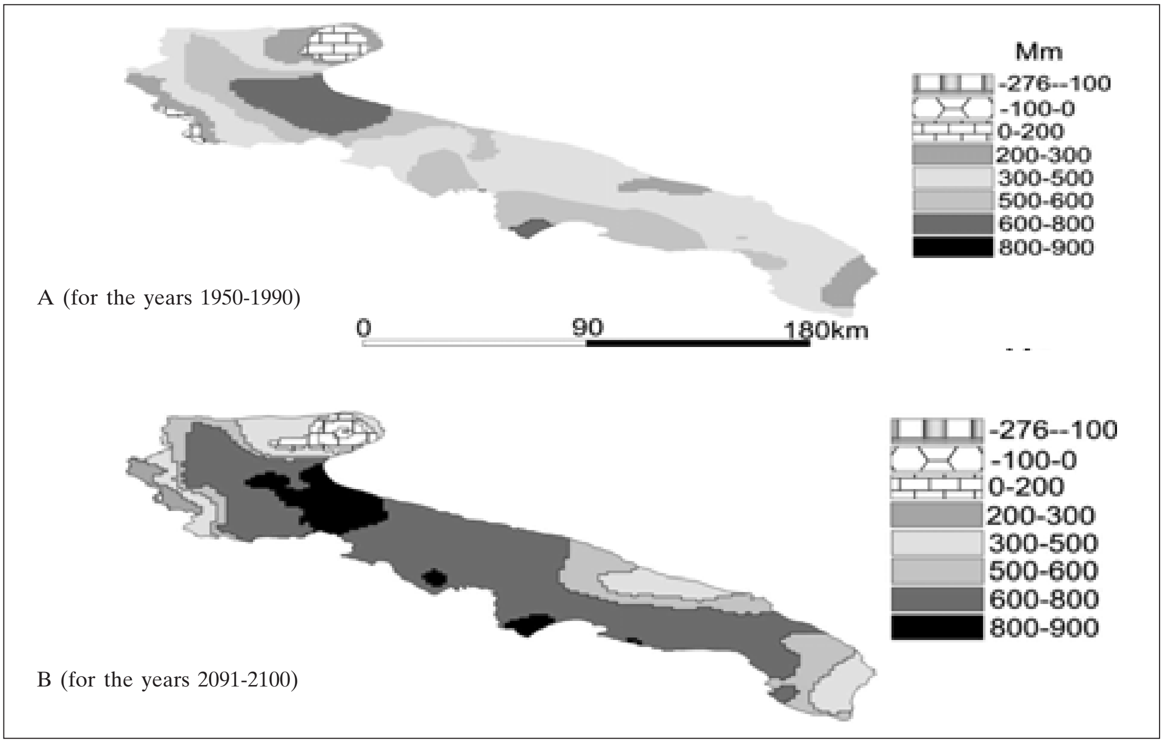

Figure 4. Climate water deficit maps of Apulia region.

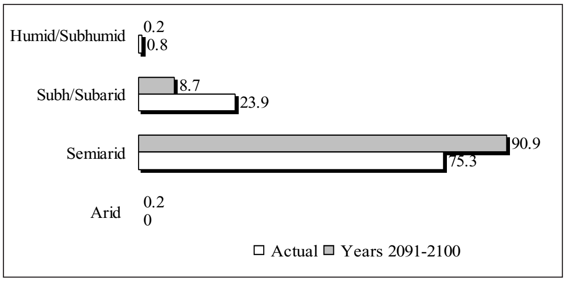

Figure 5. Climatic classes as percentage of the Apulia region at the present time and by the end of 21st Century.

as humid and enlargement of the arid zones (Fig. 5). The areas presently classified as subhumid/subarid will be characterized as semiarid zones by the end of the 21st Century. In fact, it is expected that the total regional area converted from a subhumid/subarid to a semiarid climate will be about 15% of the Apulian territory. Moreover, in those areas predicted to fall within the arid climate category, the Eto values will be three times higher than the precipitation. However, these specific climatic conditions probably will occur in only a few limited zones with a total surface area of less than 50 km^2.

According to the Thornthwaite classification three climatic groups are currently represented in the region (second, third and fourth mesothermic). However, by the end of this century only two of these are likely to remain, while the second mesothermic group will have disappeared completely. In fact, the foreseen increase in Eto will also enhance thermal efficiency and thus will shift the relevant graphs from second and third mesothermic to fourth mesothermic. A large expansion of the fourth mesothermic group is thus predicted and, by the end of this century, this category could represent 98.5% of

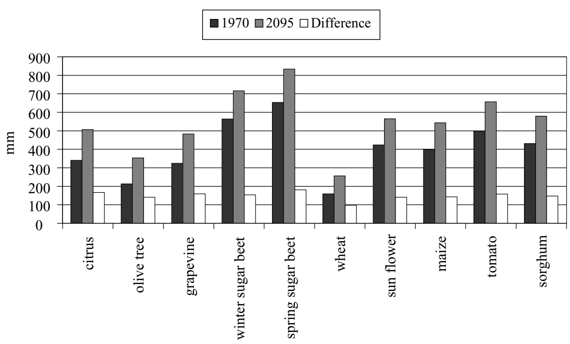

Figure 6. Annual NIR of ten major crops in the Apulia region.

the Apulian territory, compared to about 73% of the region under present-day conditions. This means that the annual ETo would be greater than 997 mm in 98.5% of the region, while at any other location in the Apulia region it would be greater than 855 mm.

This study also has demonstrated that the net irrigation requirements (NIR) for the ten major crops of the Apulia territory will increase significantly in the future. The predicted increase of NIR by the end of the 21st Century is highest for olive trees (65%), followed by wheat (61%), grapevines (49%) and citrus crops (48%), whereas it is slightly lower for maize (35%), sorghum (34%), sunflower (33%), tomato (31%), winter and spring sugar beet (both 27%) (Fig. 5). In almost all cases, the highest increase of NIR is foreseen for those months when the crops are the most sensitive to water stress, with significant negative consequences for their growth. These results agree closely with those obtained in Southern Africa for the Malibamatsama basin, 3240 km^2 in Lesotho where the main irrigated crops are wheat, cotton, maize, tea and sugar beet. Climate change simulations for this region have been obtained using a general circulation model that involves a doubling of CO_2 and the results reveal a 65% increase in irrigation water demands over the next 50 years (Sherman, 1992). Nevertheless, in the present study the net irrigation requirement for wheat, maize and sugar beet could increase by an average of 42% over the next 100 years.

A study of the Texas Edwards Aquifer (Chen et al., 2001) reported that, under the Hadley Centre simulator scenario, by the year 2090 the irrigation water requirement for maize will increase by 31.32%. According to our study, the water requirement of maize in the Apulia region will increase by 35% over the same time period (Fig. 6).

4. Conclusions

The results obtained in this work indicated that an increase of temperature and ETo and a reduction of precipitation (with concentration in winter period) is expected in the future. These results largely coincide with the results of some other analysis on climate changes in the Mediterranean region (Jeftic, 1993; Guy Pe'er et al., 2000) and also in some other areas (IUCC, 1994). The magnitude of these changes varies locally and it would have significant influence on the climatic water deficit in the region and could contribute to further aggravation of the situation related to agricultural production in the Apulia region. In fact, the trend of variation of climatic variables may increase crop water demand and reduce volume of water in the water supply systems. Moreover, higher temperatures may lead not only to the crop water stress but also to the crop heat stress and decrease in crop growth and yield productivity, especially for crops with specific temperature requirements, such as corn, soybeans and wheat. Also, the periods with temperature above average seasonal values may influence the expansion of agricultural pests and/or the acceleration of their life cycle. In fact, it is foreseen that growing period of many field crops would shift for a couple of weeks anticipating initial stage. Also, in some cases, due to higher temperatures during the growth, a decrease of growing cycle and anticipated maturation could be expected.

One of the main scopes of this study on climate change is to assess if water resources will be sustainable for agricultural production. Sustainability will be most influenced by adaptive responses. In addition to increasing CWD and NIR, another factor could create problems such as limited water resources for crop production. For this reason some adaptation options must be considered to face the future problems of water shortage.

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