Estimation of Evapotranspiration under the Effect of Climate Change in Egypt

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Abstract Accurate estimation of evapotranspiration is important for water resources management. In this study, using historical meteorological data of 21 stations, the FAO Penman-Monteith method (FAO56-PM) was applied to predict the reference evapotranspiration (ET_o) in Egypt during the late of this century (2071–2100) under the effect of the representative concentration pathways scenario (RCP4.5). The highest values of ET_o were recorded in the southern part of the country with an average of 7.53 mm/day in Asyut. These values gradually decreased from south to north, where the lowest ET_o was recorded in the northern part of the country with an average of 3.73 mm/day in Baltim. ET_o is expected to increase at the late of the century throughout the country, and the highest values will occur in the Western Desert (53% in Kharga). On the other hand, the northern part of the country will witness a slight increase in ET_o to a maximum of 8% in Baltim. Moreover, the increase of ET_o in the summer season is more significant than in other seasons. These results would help in impact assessment and adaptation strategies of climate change impacts on evapotranspiration in Egypt.

Keywords: Evapotranspiration, Penman-Monteith, Climate Change, Temperature, Egypt.

1. Introduction

Knowledge of the exact amount of crop water consumption is very important for water resources planning. Evapotranspiration (ET) is an important component of hydrological processes. Reference evapotranspiration (ET_o) is the evapotranspiration rate from a reference surface (hypothetical grass with specific characteristics) and is considered a climatic parameter that expresses the power of the evaporation of the atmosphere (Allen et al. 1998). Thus, ET is highly sensitive to any change in climatic parameters, and the amount and change in ET are complicated to estimate due to the multiplicity of factors affecting it.

Climate change has serious consequences especially in developing and poor countries that do not have the ability to recover from the effects of climate change due to rapid population growth and the alarmingly growing demands of food that worsened the conditions of these regions (IPCC 2013). Climate change is expected to significantly affect ET, which is mainly temperature dependent. The global average surface air temperature has increased by 0.6±0.2°C since the end of 19^{th} century and is expected to increase by 0.4–1.7°C at the end of 21^{st} century for the low-emission scenario and 1.4–4.8°C for the high-emission scenario (IPCC 2013). Changes in meteorological variables may cause a rise in ET such as Northeast Asia (You et al. 2019), humid areas of Iran (Nouri and Bannayan 2019), majority of China (Xu et al. 2018), Argentina (D'Andrea et al. 2019), Romania (Prăvălie et al. 2019), and Egypt (Yassen et al. 2020), or a decrease in ET such as the Tibetan Highlands (Zhang et al. 2019), the West Liao River basin in China (Gao et al. 2017), and Brazil (Júnior et al. 2019).

The Middle East and North Africa (MENA) is considered one of the most water-scarce regions in the entire globe (Terink et al. 2013). Thus, many studies have concerned to estimate the potential evapotranspiration in MENA, especially in the context of climate change. Treink et al. (2013) investigated the impact of climate change on ET in 22 countries in MENA, using the A1B scenario of nine global circulation models (GCMs) during two different future periods (2020 - 2030) and (2040 - 2050). The results showed an increase in the average annual ET_o for both future periods, with the largest increases in the farthest period. For example, Abdrabbo et al. (2015) investigated the variability of ET_o in three different regions in Egypt (Nile Delta, Middle Egypt, and Upper Egypt) under the four RCP scenarios. They concluded that the annual ET_o would increase for all future periods and for all regions with uneven values.

The main objective of this study is to investigate the spatial and temporal variability of the reference evapotranspiration at the end of the century (2071–2100) under the effect of the RCP4.5 scenario, using the FAO Penman-Monteith method (FAO56-PM), after correcting the temperature indices by the variance scaling method.

2. Methodology

2.1. Data

This work includes two types of dataset: observed and simulated data. Both datasets are daily maximum and minimum temperature, mean dew point, adjusted wind speed at 2 m from sea surface, and radiation. The observed data comprises 21 stations distributed across the country from 2001 to 2005. These data were derived from the National Oceanic and Atmospheric Administration

(NOAA) (https://www.noaa.gov/) as observed point data except for radiation data which were obtained from NASA (https://power.larc.nasa.gov/data-access) as gridded observed data. The climate variables outputs of the regional climate model "RCA4, MPI-ESM-LR", developed by SMHI (Swedish Meteorological and Hydrological Institute) was considered in this study as future simulated gridded data of RCP4.5 scenario from 2071 to 2100. The data was obtained from the CORDEX project (https://esg-dn1.nsc.liu.se/projects/cordex/), with a grid spacing of 0.44° × 0.44°.

2.2. The FAO Penman Monteith Approach

The FAO Penman Monteith method (FAO56-PM) was introduced by the Food and Agriculture Organization of United Nations (FAO) in paper 56 (Allen et al. 1998) and is the most widely used method for estimating ET_o due to its good performance in different climatic regions. The method considers several climatic variables affecting ET_o, as shown in Eq. 1.

$$ET_O = \frac{0.408\Delta(R_n - G) + \Upsilon\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \Upsilon(1 + 0.34u_2)} \quad (1)$$

Where ET_o is the reference daily evapotranspiration (mm day^{-1}), Δ is the slope of the vapor pressure curve (kPa $^oC^{-1}$), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}) which may be ignored for daily ET_o, ϒ is the psychometric constant (kPa $^oC^{-1}$), T is the mean air temperature computed as follow $(T_{max}+T_{min})/2$ (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure of the air (kPa), and e_a is the actual vapor pressure (kPa).

3. Results

After correcting the RCM simulation temperature data by the variance method, the FAO56-PM method was used to predict ETo in Egypt over the period (2071-2100) under the RCP4.5 scenario (Fig. 1). The results proved that all stations are expected to witness an increase in ET_o at the end of the century. The maximum (minimum) increase of ETo will be 53% (8%), recorded at Kharga (Asyut) station. All months will witness increases except for January and February, when ET_o values may decrease of about 12% and 18%, respectively. June and July are expected to record the highest evapotranspiration during the end of the century, with an average of 10.5 mm/day.

4. Conclusions

This paper presented a picture of the expected future evapotranspiration in Egypt through the outputs of the corrected regional climate model. RCM simulation data were corrected by the variance method for the future period (2071–2100) under the RCP4.5. The rate of evapotranspiration for all stations will increase by the end of the century when the expected increase in ET_o is in the range of 8–53%. For seasonal changes, increases in ET_o are expected in all months except for two months: January and February. Summer will witness the most increase in ET_o, with the highest value of 10.5 mm/day in June and July. In contrast, ET_o in winter is expected to decline by 12% and 18%, for January and February, respectively. Spatially, the Western Desert and Upper Egypt are the regions most affected by climate change, unlike the northern region of Egypt. These ET_o increases may have negative impacts on agricultural production and water resources availability.

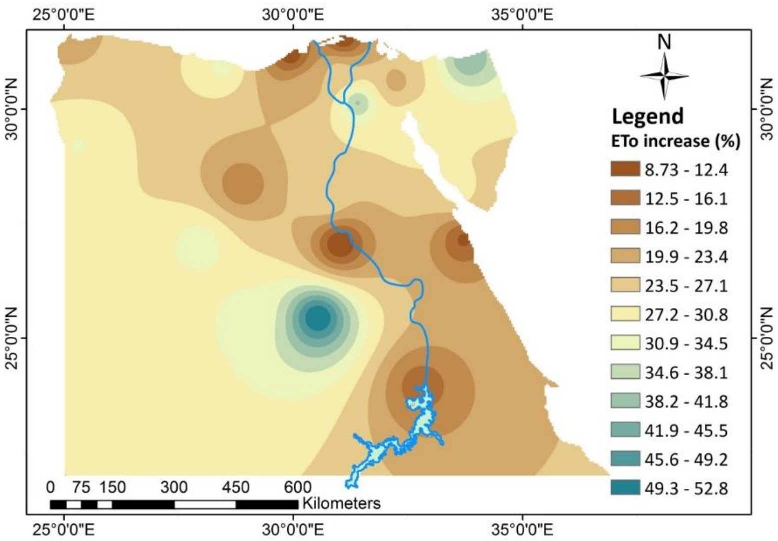

Figure 1. Spatial distribution in the increase in average daily evapotranspiration (%) in Egypt for the period (2071-2100) compared to the reference period (2001-2005) under the RCP4.5 scenario

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