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Original Research

Spatio-Temporal Variability and Trends of Penman-Monteith Reference Evapotranspiration (FAO-56) in 1971-2010 under Climatic Conditions of Poland

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Abstract

The trends of the seasonal (April-September) and monthly reference evapotranspiration time series were analyzed using linear regression. In addition, the trends of air temperature and sunshine hours also were investigated to show possible causes of the increase in reference evapotranspiration. The spatial variability of reference evapotranspiration was lower than the temporal variability and is similar to the spatial distribution of precipitation in the area of Poland. The highest reference evapotranspiration was recorded in the region with the lowest rainfall. The statistically significant linear increasing trends of reference evapotranspiration were determined at each analyzed station in 1971-2010. The increase in the growing season sum of reference evapotranspiration, averaged over 18 stations, was 30 mm per 10 years. The significant increase in reference evapotranspiration can be explained by the statistically significant increasing trends of air temperature and sunshine hours.

Keywords: evapotranspiration, crop water requirement, irrigation, observed trend, climate change

Introduction

In agriculture crop water use is determined by crop evapotranspiration. Reference, potential, and actual evapotranspiration are distinguished. The potential evapotranspiration of a given crop is defined as soil evaporation and plant transpiration under unlimited soil water supply and actual meteorological conditions. The actual evapotranspiration is the amount of water transpired from plants and evaporated from soil surface under actual meteorological conditions and under non-optimal soil, biological, management, and environmental conditions. The evapotranspiration from a reference surface is called the reference evapotranspiration (ET_o). A large uniform grass (or alfalfa) field is considered worldwide as reference surface. The only factors affecting ET_o are climatic parameters. ET_o is an agroclimatic parameter and can be computed from weather data. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider crop and soil factors [1].

Reference evapotranspiration is an important agrometeorological parameter for climatological and hydrological studies, as well as for irrigation planning and management. Reference evapotranspiration can be used to calculate actual evapotranspiration from cropped surfaces other than the reference surface with the crop factor method using the crop coefficient (under standard conditions) and water stress coefficient (under soil water stress conditions).

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To estimate crop water requirements, one can relate potential evapotranspiration from the cropped soil with an optimum water supply to an estimated reference evapotranspiration by means of a crop coefficient.

The FAO Penman-Monteith (FAO-56 or FAO-PM) method has been considered a universal standard to estimate ET_o [1-3]. There are many researchers who carried out analysis of the FAO-PM method and the reference evapotranspiration calculated with this method. Buttafuoco et al. [4], McVicar et al. [5], and Song et al. [6] analyzed spatial distribution of reference evapotranspiration in different regions and scales. Allen et al. [7, 8], Buttafuoco et al. [4], and Fitzmaurice and Beswick [9] investigated accuracy and sensivity of the FAO-PM method. Popova et al. [10] analyzed the accuracy of different procedures to estimate missing data required in the FAO Penman-Monteith method in reference to southern Bulgaria. Maulé et al. [11], Paltineanu et al. [12], and Sumner and Jacobs [13] analyzed the FAO-PM method in relation to other methods of calculating reference evapotranspiration.

There are also many studies on the impact of climate change on observed meteorological elements, mostly temperature and precipitation, but long-term changes in reference evapotranspiration have rarely been explored. In this study, an attempt is made to examine the spatio-temporal variability and trends of the Penman-Monteith reference evapotranspiration in Poland in 1971-2010. It was also important to discover whether trends of temperature and sunshine as the main factors determining evapotranspiration coincide with the trends of reference evapotranspiration.

Methods and Materials

By defining the reference crop as an actively growing and well watered green grass surface with a height of 0.12 m having a surface resistance of 70 s·m^{-1} and an albedo of 0.23, reference evapotranspiration was calculated from the Penman-Monteith equation as [1]:

$$ET_o = \frac{0.408\Delta R_n + \gamma \frac{900}{T+273} u(e_s - e_a)}{\Delta + \gamma(1+0.34u)} \qquad (1)$$

...where:
ET_o– reference evapotranspiration (mm·day^{-1})
R_n – net radiation (MJ·m^{-2}·day^{-1})
T – mean daily air temperature at 2 m height (ºC)
u – wind speed at 2 m height (m·s^{-1})
e_s – saturation vapour pressure (kPa)
e_a – actual vapour pressure (kPa)
Δ – slope of the vapour pressure curve (kPa·ºC^{-1})
γ – psychrometric constant (kPa·ºC^{-1}).

For the purpose of this study ET_o was calculated with a 10-day time step using mean 10-day weather data. Several data in Equation (1) were not measured directly and they were computed. The methods of computation of such data used in the study are presented in details by Łabędzki et al. [14, 15].

Table 1. Geographical location of the studied meteorological stations.

No.	Station	Altitude (m a.s.l.)*	Latitude	Longitude
1	Białystok	139	53º13'	23º10'
2	Biebrza	117	53º39'	22º36'
3	Bydgoszcz	46	53º08'	18º01'
4	Częstochowa	261	50º49'	19º06'
5	Elbląg	38	54º10'	19º26'
6	Gorzów	65	52º44'	15º15'
7	Kielce	256	50º51'	20º37'
8	Koszalin	33	54º12'	16º09'
9	Kraków	209	50º04'	19º57'
10	Lublin	171	51º14'	22º34'
11	Łódź	184	51º44'	19º24'
12	Mława	141	53º06'	20º21'
13	Opole	176	50º40'	17º58'
14	Poznań	86	52º25'	16º50'
15	Rzeszów	200	50º06'	22º03'
16	Szczecin	1	53º24'	14º37'
17	Warszawa	106	52º09'	20º59'
18	Wrocław	116	51º06'	17º05'

*m a.s.l. – meters above mean sea level

ET_o was calculated in the growing period (April-September) of 1971-2010 for each month and the whole period. Using Equation (1) the mean 10(11)-day values of ET_o were calculated using 10(11)-day-averages of R_n, T, u, e_s, and e_a. Then the 10(11)-day sums of ET_o were calculated by multiplying the mean 10(11)-day values by 10 or 11. The monthly and the whole period sums were computed as the sums of the 10(11)-day sums.

The daily records of meteorological parameters came from select meteorological stations located in different regions of Poland (Table 1, Fig. 1). The stations are kept by the Institute of Meteorology and Water Management (stations Nos. 1 and 4-18) and by the Institute of Technology and Life Sciences (stations Nos. 2 and 3). The measured meteorological parameters include air temperature, air humidity, sunshine hours, and wind velocity.

The statistical analysis was performed to get the values of mean, minimum, maximum, standard deviation, variability coefficient, and median. Statistical parameters characterizing the temporal variability of ET_o are determined using ET_o averaged over 18 stations in each year. Statistical parameters characterizing the spatial variability of ET_o are determined using ET_o averaged over 40 years at each station.

Trends of ET_o in the 40-year time series were established to check if reference evapotranspiration has increased or decreased significantly in 1971-2010. Linear trends were fitted using ordinary least squares regression. The trends were computed for individual stations and for average ET_o over all stations, in each month from April to September and in the whole period. The statistical significance of the trends was assessed at the 5% level using the t-test. The main statistical parameter drawn from the regression analysis, the slope, indicates the mean temporal change of the studied variable. Positive values of the slope show increasing trends, while negative values indicate decreasing trends. The total change during the period under observation is obtained by multiplying the slope by the number of years or the change during a decade (10-year period) by multiplying the slope by 10.

The maps of the spatial distribution of precipitation, temperature, reference evapotranspiration, and its trend parameters were created using the Regularized Spline Radial Basic Function method with the Spatial Analyst Module of ArcView GIS 9.1.

Results and Discussion

Climatological Characteristics

Poland is situated in the Great European Plain between the Baltic Sea and the Carpathian Mountains. It is located in a transitory temperate climate zone, influenced by a mild oceanic climate from the west and a dry continental climate from the east. Climatic conditions in Poland are characterized by considerable variability in weather during long periods of time (years) as well as short periods (days, weeks, months).

The annual precipitation amounts to 600 mm. It reaches 350 mm on average during the growing period (April-September). In this period precipitation ranges from 300 mm in the central part to 400 mm in northern Poland and to 600 mm in southern Poland (Fig. 2). The annual mean temperature is 7.5ºC and in the growing season is 14.3ºC (Fig. 3). Averages of temperature in Poland in the 20th century varied from 6ºC to over 9ºC, with a tendency for 7-year periodicity and reveal an increasing trend, which means the warming up reaching 0.9ºC per 100 years [16]. The mean temperature ranges from -2.5ºC in January to 18ºC in July. The daily maximum temperature sometimes rises above 30ºC in summer.

Fig. 1. Geographical location of the studied meteorological stations in Poland (1 – the number of the station from Table 1).

Fig. 2. Precipitation (mm) in the growing season (April-September), mean values in 1971-2010.

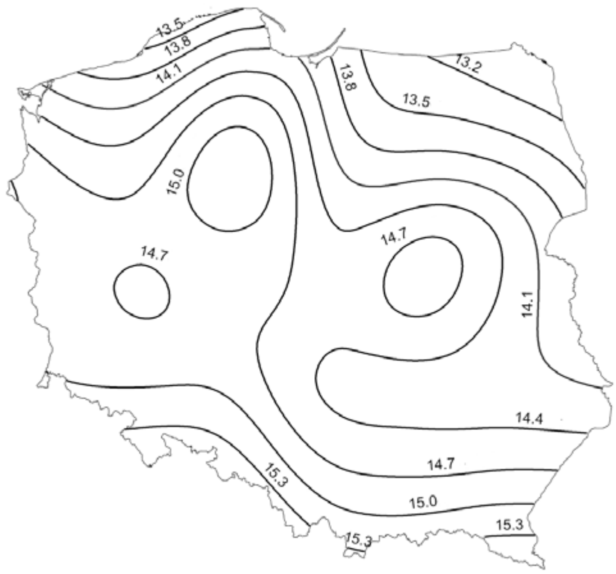

Fig. 3. Temperature (ºC) in the growing season (April-September), mean values in 1971-2010.

Due to the shortage of precipitation and the increase trend of temperature, drought frequency has increased, particularly during the last decade. Central, northwestern and mideastern parts are most threatened by droughts. The growing season rainfall amount is often less than 300 mm. This area sometimes experiences extremely long periods without rain. Droughts appear once every 4-5 years in central Poland [17]. Drought usually begins in western Poland,

Table 2. Statistics of temporal variability of ET_o averaged over 18 stations.

Parameter	April	May	June	July	Aug.	Sept.	April-Sept.
Mean (mm)	61	91	103	107	90	52	504
Minimum (mm)	47	67	77	75	71	41	404
Maximum (mm)	90	112	134	159	111	68	591
Median (mm)	58	92	101	108	90	50	504
Standard deviation (mm)	9	11	14	18	11	8	48
Variability coefficient (%)	16	12	14	17	12	15	9

Table 3. Statistics of spatial variability of ET_o averaged over 40 years.

Parameter	April	May	June	July	Aug.	Sept.	April-Sept.
Mean (mm)	61	91	103	107	90	52	504
Minimum (mm)	53	86	98	99	83	44	468
Maximum (mm)	64	97	110	113	96	57	531
Median (mm)	61	91	103	107	90	53	507
Standard deviation (mm)	3	4	4	4	4	3	21
Variability coefficient (%)	5	4	4	4	5	6	4

moves through the central part and eventually reaches the eastern side. Droughts have become a severe problem in Polish agriculture. They are the main reason for the decline in crop yields.

Temporal Variability of Reference Evapotranspiration ET_o

The monthly and growing season sums of ET_o, averaged over 18 stations, characterize the multi-year mean reference evapotranspiration in Poland. In particular months it ranges from 52 mm in September to 107 mm in July (Table 2). This means a mean daily reference evapotranspiration from 1.7 mm·day^{-1} to 3.5 mm·day^{-1}, respectively. The highest monthly sum (159 mm) was recorded in July 2006 and the lowest (41 mm) in September 1978.

In the whole growing period, from April to September, ET_o amounts to 504 mm. Taking into account the average precipitation in this period equal to 370 mm, water deficit can be expected in Poland, on average. During 1971-2010, the lowest whole-country mean ET_o (404 mm) occurred in 1980 and the highest ET_o (591 mm) in 2006 (Table 2). 1980 was a very wet year with the highest precipitation in most regions of Poland, whereas in 2006 severe drought occurred all over the country, caused by very low precipitation, high air temperature, and high insolation. The close relationship between reference evapotranspiration and precipitation is a characteristic feature of a transitory temperate climate. Reference evapotranspiration had rather high temporal variability in the multi-year period, with the variability coefficient of 12-16% for the monthly sums and 9% for the sums in the growing season. This is the other special feature of climate in Poland.

ET_o changed in a wide range in 1971-2010. The amplitude (maximum-minimum) of the ET_o sums in the growing season was the lowest in northern Poland (161 mm) and the highest in central Poland (298 mm). It shows that meteorological conditions were more stable in northern Poland than in central.

Spatial Variability of Reference Evapotranspiration ET_o

The monthly and the growing season sums of ET_o, averaged over 40 years at each station, characterise the spatial variability of long-term average reference evapotranspiration. The minimum multi-year average ET_o in the growing season (468 mm) was recorded at station No. 2, located in the northeastern part of Poland (Table 3). The maximum temporal average sum of ET_o (531 mm) was observed in the central part (the station No. 11).

Similar to the spatially averaged ET_o, the monthly sums of ET_o, averaged in time, were the highest in July (113 mm) in central Poland and the lowest in September (44 mm) in northeastern part (Table 3).

The spatial variability of reference evapotranspiration (the variability coefficient 4-6%) was lower than the temporal variability. This means the greater differentation of the reference evapotranspiration within the years than in the space.

Table 4. Absolute minimum and maximum sums of ET_o (mm) in the growing season (April-September) at 18 stations in 1971-2010.

Period	Abs min	Abs max
April	36	99
May	55	128
June	68	162
July	61	189
August	60	131
September	31	83
April-September	353	694

Table 5. Trends of mean ET_o in the growing season (April-September) at 18 stations in 1971-2010.

Period	Increase (mm·decade^{-1})	Determination coefficient R^2
April	5.7	0.494
May	3.6	0.151
June	6.1	0.262
July	7.7	0.263
August	4.3	0.211
September	2.5	0.143
April-September	29.9	0.537

The absolute minimum reference evapotranspiration sum in the growing season at all stations and in all years amounted to 353 mm and was determined in 1980 in northeastern Poland (station No. 2) (Table 4). The absolute maximum was equal to 694 mm in 2006 in central Poland (station No. 17).

A spatial differentiation of the reference evapotranspiration is observed in Poland (Fig. 4). The growing season sum of reference evapotranspiration, calculated with the Penman-Monteith method, ranges in the area of the country from 460 to 530 mm in an average year. The higher reference evapotranspiration was recorded in central Poland from west to east. The highest values occurred in the area with station Nos. 6, 11, 14, and 17. In comparing with other regions, this is the region of Poland with low rainfall that is most threatened by meteorological droughts. In connection with high reference evapotranspiration the region is threatened by agricultural droughts.

Similar to the sum of the reference evapotranspiration in the growing season, the highest values of the monthly sums occurred in the midwestern part of Poland, reaching 110 mm in July in that region. The lowest ET_o is observed in April and September, being twice less than in July.

Trends of Reference Evapotranspiration ET_o

The linear increasing trends of ET_o were determined at each analyzed station as well as of the 18-station mean ET_o in 1971-2010. They are statistically significant at the probability level $p<0.05$.

The increase in the growing season sum of ET_o, averaged over 18 stations, is 29.9 mm per 10 years and the determination coefficient of the linear trend $R^2 = 0.537$ (Table 5, Fig. 5). The trends of the 18-station mean ET_o are also significant statistically in each month from April to September (Table 5). The greatest increase is observed in July (7.7 mm per 10 years).

The trend of the growing season sum of ET_o shows the increase of 9-54 mm·decade^{-1} at the analyzed stations (Fig. 6). The biggest increase is observed at stations 7 (Warszawa) and 8 (Wrocław), the lowest at station 2 (Bydgoszcz). The spatial distribution of the determination coefficient R^2 of the linear trend changes from 0.08 to 0.66, with highest value at station 7 (Warszawa) and the lowest at station 2 (Bydgoszcz) (Fig. 7). All trends are statistically significant at probability level $p<0.05$ in the whole growing season and in each month.

The changes of reference evapotranspiration ET_o in the analyzed 40 years are also seen when taking account the decades (Table 6). In the first decade (1971-80) ET_o in the growing season was the least (463 mm). Beginning from 1971 the 10-year mean ET_o increased permanently, reaching the highest value in 2001-10 (555 mm). This tendency is observed in each month as well as in the whole growing period at each station, except for June, when ET_o was higher in the 1970s than the 1980s, also at each station.

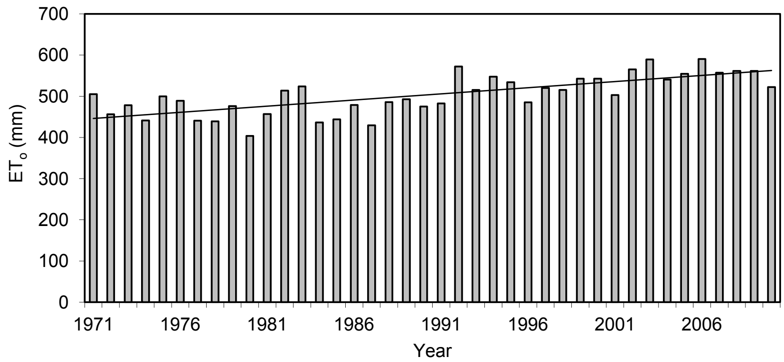

Fig. 5. Linear trend of mean sum of ET_o (mm) over 18 stations in the growing season (April-September) in 1971-2010.

Table 6. ET_o (mm) in the decades of 1971-2010, averaged for 18 stations.

Years	April	May	June	July	Aug.	Sept.	April-Sept.
1971-1980	53	85	98	95	83	49	463
1981-1990	57	90	92	101	86	49	474
1991-2000	64	95	108	111	95	53	526
2001-2010	69	96	114	121	97	57	555
1971-2010	61	91	103	107	90	52	504

Table 7. Increase of mean air temperature and mean daily sunshine duration in the growing season (April-September) at 18 stations in 1971-2010.

Period	Temperature		Sunshine duration	
	Increase (ºC·decade^{-1})	Significance level (p-value)	Increase (h·decade^{-1})	Significance level (p-value)
April	0.75	<0.0001	0.61	<0.001
May	0.28	0.174	0.37	0.048
June	0.37	0.016	0.58	0.003
July	0.69	0.003	0.65	0.006
August	0.45	0.006	0.33	0.050
September	0.29	0.132	0.39	0.027
April-September	0.47	<0.0001	0.49	<0.0001

The important question to answer in the next stage of the study was about the effect of meteorological variables on ET_o trends. Reference evapotranspiration process is mainly controlled by variations in air temperature, solar radiation, relative humidity, and wind speed. Tabari et al. [18] showed that the increasing trend in ET_o at 20 meteorological stations during 1966-2005 in the western half of Iran was mainly caused by a significant increase in air temperature. Analysis of monthly ET_o at 15 stations during 1961-2005 in the Taoer River basin in China [19] showed that maximum air temperature, mean air temperature, relative humidity, and bright sunshine hours were main climate variables responsible for the variability in ET_o. Vergni and Todisco [20] proved that ET_o trends in Central Italy were mainly positive and were strictly related to the tendencies in mean temperature and mean temperature range. Espadafor

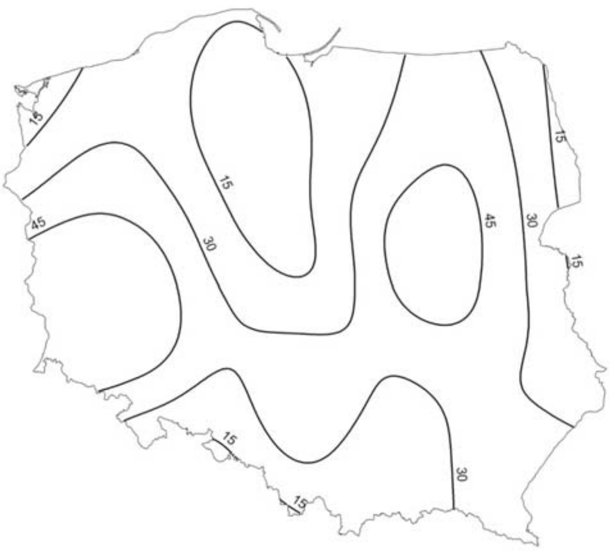

Fig. 6. Increase of ET_o (mm·decade^{-1}) in the growing season (April-September) in 1971-2010.

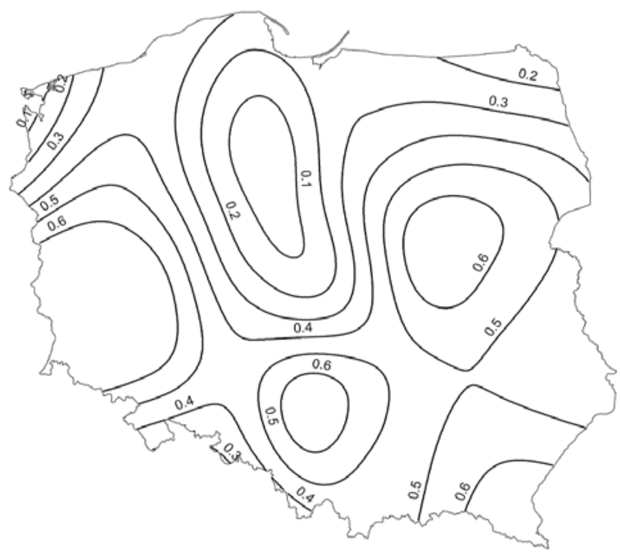

Fig. 7. Determination coefficient R^2 of the linear trend of the growing season sum of ET_o in 1971-2010.

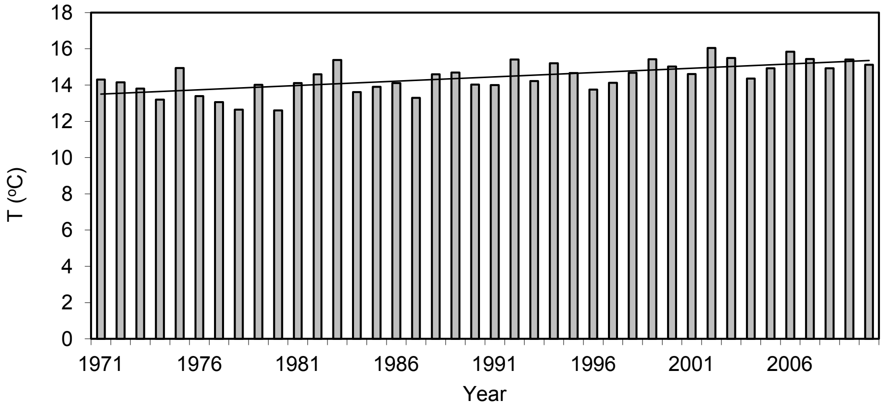

Fig. 8. Linear trend of mean air temperature T (ºC) over 18 stations in the growing season (April-September) in 1971-2010.

et al. [21] detected statistically significant increases in PM-ET_o in Southern Spain due to increases in air temperature and solar radiation.

Therefore, possible causes of the increase in the ET_o series were investigated in view of the trends of the meteorological variables, including air temperature and sunshine hours.

Average air temperature shows a long-term statistically significant increasing trend of 0.47ºC per 10 years in the growing season (April-September) (Fig. 8). The highest increase is observed in April (0.75ºC·decade^{-1}) and in July (0.69ºC·decade^{-1}); the lowest in May and September, and they were not statistically significant (Table 7).

Sunshine duration also increased significantly in 1971-2010. Mean daily sunshine hours increased by 0.49 h·decade^{-1} when concerning the whole growing period (Fig. 9). The increasing trends of 0.61 and 0.65 h per 10 years are observed in April and May, respectively. The increase in August was the lowest, not proven statistically (Table 7).

The significant increase in ET_o is an effect of the increasing trends of air temperature and sunshine hours, observed in the analyzed 40 years in Poland. The observed increase in temperature in Poland in the growing season of 1971-2010 is higher than that related by Beniston and Tol [22] for most of Europe during the 20th century, which amounts to 0.8ºC in annual mean temperature. Kożuchowski and Żmudzka [16] determined that average temperature in Poland in the 20th century increased 0.9ºC per 100 years. For Polish conditions Kępińska-Kasprzak et al. [23] showed a significant increase in temperature and sunshine hours in one region of the country (Wielkopolska) during 1966-85, effecting the increase of reference evaporation. The observed trend in increased temperature in Poland is in good agreement with trends observed in other European countries. An overview of climatic trends in Germany [24] shows that the annual average temperature increased by 1.1ºC between 1981 and 2000. Mladenova and Varlev [25] noted in 1970-2000 an increase in the average temperature sum in the vegetation period by about 200ºC in Bulgaria, which meant about 1ºC of mean temperature. Ljubenkov [26] has proved that in Korčula Island in Croatia temperature had an upward trend in 1948-2008 with an increase of about 1.0ºC in 60 years.

Conclusions

This paper has concentrated on spatial and temporal variability of Penman-Monteith reference evapotranspiration in Poland in 1971-2010. Using 10-day weather data from 18 weather stations, the PM reference evapotranspiration was calculated. The analysis of temporal and spatial variability of the PM reference evapotranspiration was made. The trends of the seasonal (April-September) and monthly reference evapotranspiration time series were analyzed with linear regression during 1971-2010. In addition, the trends of air temperature and sunshine hours were also

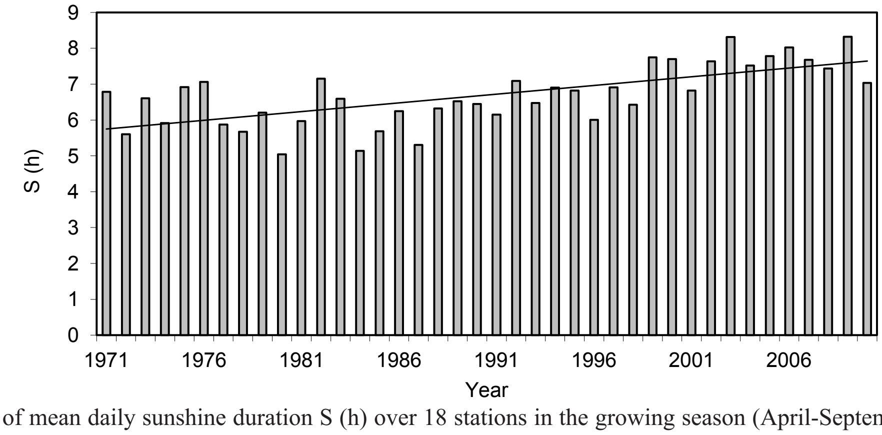

Fig. 9. Linear trend of mean daily sunshine duration S (h) over 18 stations in the growing season (April-September) in 1971-2010.

investigated to show possible causes of the increase in reference evapotranspiration.

The sum of reference evapotranspiration in the growing season from April to September exceeds 500 mm in most areas of Poland. Averaged over 40 years and 18 stations it amounts to 504 mm. The monthly sums of reference evapotranspiration, averaged over 18 stations, range from 52 mm in September to 107 mm in July.

The spatial variability of reference evapotranspiration was lower than the temporal variability. This means the bigger differentation of the reference evapotranspiration among years than among stations.

As a general rule, reference evapotranspiration isolines as yielded by the Penman-Monteith method showed a characteristic pattern, by decreasing from the central part to the northern and southern parts of Poland as well as to the eastern part. They are traced almost west-east in the central part and north-south in the eastern part. The spatial distribution of reference evapotranspitration in the area of Poland is similar to the spatial distribution of precipitation. The highest reference evapotranspiration was recorded in the region with the lowest rainfall.

The statistically significant linear increasing trends of reference evapotranspiration were determined at each analyzed station in 1971-2010. The increase in the growing season sum of ET_o, averaged over 18 stations, is 30 mm per 10 years. The significant increase in ET_o can be explained by the statistically significant increasing trends of air temperature (mean in the growing season by 0.5ºC per 10 years) and sunshine hours (mean daily sunshine hours by 0.5 h per 10 years).

In most of the country reference evapotranspiration exceeds precipitation and this is the reason of water shortage for crops. This tendency can be expected to grow with the foreseen climate warming. Future studies should be addressed to answer the question if the area of Poland becomes drier and warmer under predicted climate change in the 21st century and to quantify how predicted climate change will affect reference evapotranspiration, crop water demand, water deficit, water availability, and irrigation water requirements.

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References

1. ALLEN R.G., PEREIRA L.S., RAES D., SMITH M. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. FAO, Rome. pp. 300, **1998**.
2. ALLEN R.G., JENSEN M.E., WRIGHT J.L., BURMAN R.D. Operational estimate of reference evapotranspiration. Agron. J. **81**, 650, **1989**.
3. ALLEN R.G., SMITH M., PERRIER A., PEREIRA L.S. An update for the definition of reference evapotranspiration. ICID Bull. **43**, 1, **1994**.
4. BUTTAFUOCO G., CALOIERO T., COSCARELLI R. Spatial uncertainty assessment in modelling reference evapotranspiration at regional scale. Hydrol. Earth Syst. Sci. Discuss. **7**, 4567, **2010**. DOI:10.5194/hessd-7-4567-2010.
5. McVICAR T.R., van NIEL T.G., LI L., HUTCHINSON M.F., MU X., LIU Z. Spatially distributing monthly reference evapotranspiration and pan evaporation considering topographic influences. J. Hydrol. **338**, 196, **2007**. DOI: 10.1016/j.jhydrol.2007.02.018.
6. SONG Z.W., ZHANG H.L., SNYDER R.L., ANDERSON F.E., CHEN F. Distribution and Trends in Reference Evapotranspiration in the North China Plain. J. Irrig. Drain. E.-ASCE **136**, 240, **2010**.
7. ALLEN R. G., CLEMMENS A.J., BURT C.M., SOLOMON K., O'HALLORAN T. Prediction accuracy for projectwide evapotranspiration using crop coefficients and reference evapotranspiration. J. Irrig. Drain. E.-ASCE **131**, 24, **2005**.
8. ALLEN R.G., PRUITT W.O., WRIGHT J.L., HOWELL T.A., VENTURA F., SNYDER R., ITENFISU D., STEDUTO P., BERENGENA J., YRISARRY J.B., SMITH M, PEREIRA L.S., RAES D., PERRIER A., ALVES I., WALTER I., ELLIOTT R. A recommendation on standardized surface resistance for hourly calculation of reference ET_o by the FAO56 Penman-Monteith method. Agr. Water Manage. **81**, (1-2), 1, **2006**.
9. FITZMAURICE L., BESWICK A. Sensitivity of the FAO56 crop reference evapotranspiration to different input data. Technical Report QNRM05484. Department of Natural Resources and Mines, Queensland, Australia. pp. 16, **2005**.
10. POPOVA Z., KERCHEVA M., PEREIRA L.S. Validation of the FAO methodology for computing ET_o with limited data. Application to South Bulgaria. Irrigation and Drainage. **55**, 201, **2006**. DOI: 10.1002/ird.228.
11. MAULÉ C., HELGALSON W., MCGINN S., CUTFORTH H. Estimation of standardized reference evapotranspiration on the Canadian Prairies using simple models with limited weather data. Canadian Biosystems Engineering. **48**, 1.1, **2006**.
12. PALTINEANU C., PANORAS A.G., MAVROUDIS I.G., LOUISAKIS A. Estimating reference evapotranspiration and irrigation water requirements in the Gallikos river basin, Greece. International Agrophysics. **13**, 49, **1999**.
13. SUMNER D.M., JACOBS J.M. Utility of Penman-Monteith, Priestley-Taylor, reference evapotranspiration and pan evaporation methods to estimate pasture evapotranspiration. J. Hydrol. **308**, 81, **2005**. DOI:10.1016/j.jhydrol.2004.10.023.
14. ŁABĘDZKI L., KANECKA-GESZKE E., BĄK B., SŁOWIŃSKA S. Estimating reference evapotranspiration using the FAO Penman-Monteith method for climatic conditions of Poland. In: L. Łabędzki (Editor), Evapotranspiration. Rijeka: InTech. pp. 275-294, **2011**.
15. ŁABĘDZKI L., BĄK B., KANECKA-GESZKE E. Magnitude and variability of Penman-Monteith reference evapotranspiration in the growing season of 1970-2004 in selected regions of Poland. Woda-Środowisko-Obszary Wiejskie (Water-Environment-Rural Areas). **12**, 2, (38), 159, **2012** [In Polish].

16. KOŻUCHOWSKI K., ŻMUDZKA E. 100-year series of aerially averaged temperatures and precipitation totals in Poland. In: Man and Climate in the 20th Century. Studia Geograficzne. **75**, 117, **2003**.
17. ŁABĘDZKI L. Estimation of local drought frequency in central Poland using the standardized precipitation index SPI. Irrigation and Drainage. **56**, 67, **2007**. DOI:10.1002/ird.285.
18. TABARI H., MAROFI S., AEINI A., TALAEE P.H., MOHAMMADI K. Trend analysis of reference evapotranspiration in the western half of Iran. Agr. Forest Meteorol. **151**, 128, **2011**. DOI:10.1016/j.agrformet.2010.09.009.
19. LIANG L.Q., LI L.J., LIU Q. Temporal variation of reference evapotranspiration during 1961-2005 in the Taoer River basin of Northeast China. Agr. Forest Meteorol. **150**, 298, **2010**. DOI:10.1016/j.agrformet.2009.11.014.
20. VERGNI L., TODISCO F. Spatio-temporal variability of precipitation, temperature and agricultural drought indices in Central Italy. Agr. Forest Meteorol. **151**, 301, **2011**. DOI:10.1016/j.agrformet.2010.11.005.
21. ESPADAFOR M., LORITE I.J., GAVILÁN P., BERENGENA J. An analysis of the tendency of reference evapotranspiration estimates and other climate variables during the last 45 years in Southern Spain. Agr. Water Manage. **98**, 1045, **2011**. DOI:10.1016/j.agwat.2011.01.015.
22. BENISTON M., TOL R.S.J. Europe. In: R.T. Watson et al. (Ed.), The Regional Impacts of Climate Change: an Assessment of Vulnerability. A Special Report of IPCC Working Group II. Cambridge University Press:, Cambridge, UK. pp. 149-187, **1998**.
23. KĘPIŃSKA-KASPRZAK M., MAGER P., TERLECKA M. Variability of selected climatic and hydrological elements in the context of water availability for crops. Infrastruktura i Ekologia Terenów Wiejskich (Infrastructure and Ecology of Rural Areas). **7**, 121, **2011** [In Polish].
24. JONAS M., STAEGER T., SCHÖNWIESE C.D. Calculation of the probabilities for the occurrence of extreme events due to climate change – focus Germany. UBA-Forschungsvorhaben 20141254. Institut für Atmosphäre und Umwelt, Universität Frankfurt/Main, Germany. pp 250, **2005** [In German].
25. MLADENOVA B., VARLEV I. Impact of extreme climate years on relative “yield-evapotranspiration” relationships. Journal Water Land Development. **11**, 71, **2007**.
26. LJUBENKOV I. Water resources of the island of Korčula (Croatia): availability and agricultural requirement. Journal Water Land Development. **17**, 11, **2012**.