한국농림기상학회지, 제21권 제4호(2019) (pISSN 1229-5671, eISSN 2288-1859)
Korean Journal of Agricultural and Forest Meteorology, Vol. 21, No. 4, (2019), pp. 229~237
DOI: 10.5532/KJAFM.2019.21.4.229

남한지역의 논 농업기후지대에 대한 기상자료 기반의 기준 증발산량 추정

정명표 · 허지나* · 심교문 · 김용석 · 강기경 · 최순군 · 이병태
국립농업과학원 기후변화생태과
(2019년 9월 24일 접수; 2019년 12월 6일 수정; 2019년 12월 20일 수락)

Reference evapotranspiration estimates based on meteorological variables over Korean agro-climatic zones for rice field

Myung-Pyo Jung, Jina Hur*, Kyo-Moon Shim, Yongseok Kim, Kee-Kyung Kang, Soon-Kun Choi and Byeong-Tae Lee
Climate Change & Agroecology Division, National Institute of Agricultural Sciences, Wanju-gun, Korea
(Received September 24, 2019; Revised December 6, 2019; Accepted December 20, 2019)

ABSTRACT

This study was conducted to estimate annual reference evapotranspiration (ET_0) for the agro-climatic zones for rice paddy fields in South Korea between 1980 and 2015. The daily ET_0 was estimated by applying the Penman-Monteith method to meteorological data from 61 weather stations provided by Korean Meteorological Administration (KMA). The average of annual ET_0 from 1980 to 2015 was 1334.1±33.89 mm. The ET_0 was the highest at the Southern Coastal Zone due to their higher air temperature and lower relative humidity. The ET_0 had significantly increased with 2.81 mm/yr for the whole zones over 36 years. However, the change rate of it was different among agro-climatic zones. The annual ET_0 highly increased in central zones and eastern coastal zones. In terms of correlation coefficient, the temporal change of the annual ET_0 was closely related to variations of four meteorological factors (i.e., mean, minimum temperatures, sunshine duration, and relative humidity). The results demonstrated that whole Korean agro-climatic zones have been undergoing a significant change in the annual ET_0 for the last 36 years. Understanding the spatial pattern and the long-term variation of the annual ET_0 associated with global warming would be useful to improve crop and water resource managements at each agro-climatic zone of South Korea.

***Key words*: Agro-climatic zones, Penman-Monteith method, Reference evapotranspiration**

I. Introduction

Evapotranspiration (ET) one of the most important components of hydrologic cycle process is the total of evaporation and plant transpiration from the soil and water surface to atmosphere (Sabziparvar *et al.*, 2010). It influences on crucial factors of available water resources such as plant growth, soil moisture,

* Corresponding Author : Jina Hur
(hjn586@korea.kr)

groundwater recharge, and runoff (Komatsu *et al*., 2008; Thomas, 2000). In many regions, many factors such as climate, crop, management, and environmental conditions, which affect ET, are spatially and temporally variable making it difficult to estimate actual ET (Tabari *et al*., 2012). It could be measured by a lysimeter-based method, micrometeorological approaches such as the heat balance, the Penman-Monteith combination, the aerodynamic method, and eddy covariance (Ikawa *et al.,* 2017). Also models for estimating ET that integrated the plant's physiological characteristics developed over

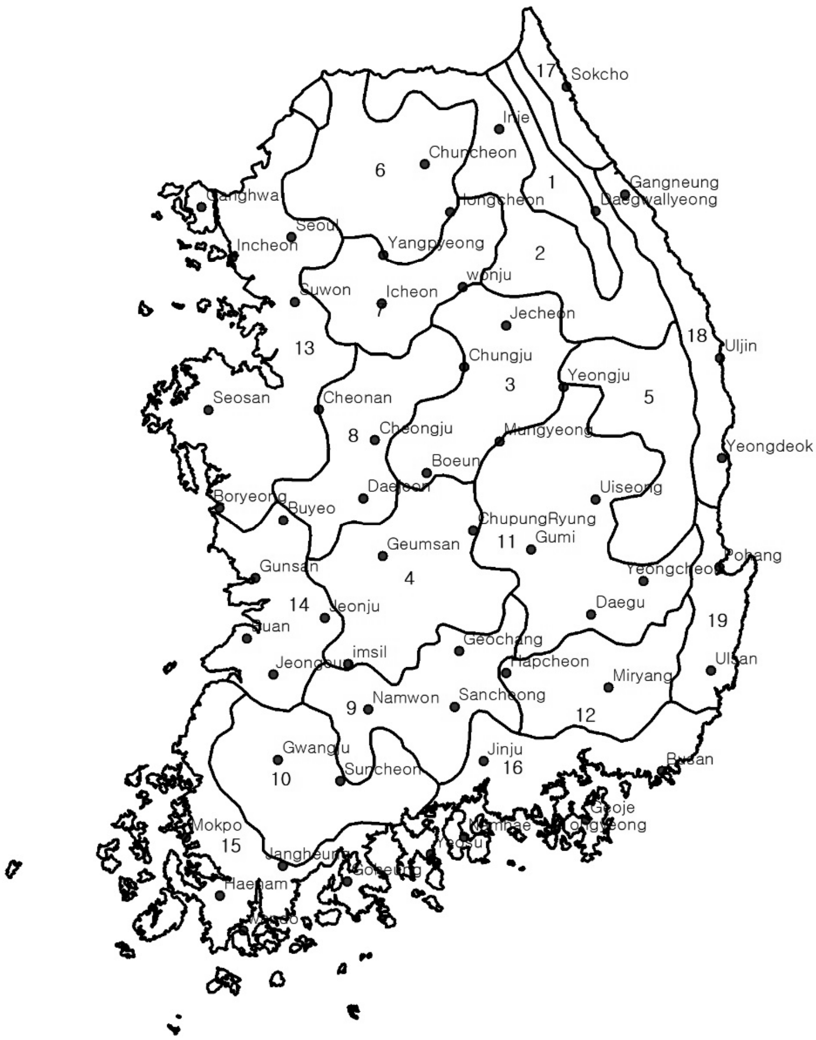

Fig. 1. The location of weather stations and agro-climatic zones in South Korea. 1: Taebaek Alpine zone, 2: Taebaek Semi-Alpine zone, 3: Sobaek Mountainous zone, 4: Noryeong Sobaek Mountainous zone, 5: Yeongnam Inland Mountainous zone, 6: Northern Central Inland zone, 7: Central Inland zone, 8: Western Sobaek Inland zone, 9: Noryeong Eastern & Western Inland zone, 10: Honam Inland zone, 11: Yeongnam Basin zone, 12: Yeongnam Inland zone, 13: Western Central Plain zone, 14: Southern Charyeong Plain zone, 15: South Western Coastal zone, 16: Southern Coastal zone, 17: North Eastern Coastal zone, 18: Central Eastern Coastal zone, 19: South Eastern Coastal zone.

the last few decades (Yoshimoto *et al.,* 2011).

Reference ET (ET_0), a potential evapotranspiration, is the rate of evapotranspiration from a hypothetical grass reference crop with a height of 0.12m, a fixed surface resistance of 70 s m^{-1}, and an albedo of 0.23. This crop should have active growth, adequate water supply, and complete shading (Allen *et al*., 1998). Because ET_0 is affected by climate parameters such as air temperature, relative humidity and wind speed, the change in the parameters on ET_0 is hard to comprehend. The accurate estimation of ET_0 and its spatiotemporal analysis are important to comprehend the influences of climate change on a hydrologic cycle.

Many studies have shown that ET_0 decreased in many areas around the world (Gao *et al*., 2006; Irmak *et al*., 2012; Jhajharia *et al*., 2012; Huo *et al*., 2013), whereas several studies reported that ET_0 increased in Asia and in Europe (Tabari *et al*., 2012, Wang and Wang, 2012; Palumbo *et al*., 2011). Although many studies have argued that climate change was the major influencing factor in ET_0 changes across the world, ET_0 change is various due to the effect of combined results of various factors (Zuo *et al*., 2005; Liu *et al*., 2010; Jhajharia *et al*., 2014). These changes in ET_0 have important affect the water resources and agricultural production under climate change.

An agro-climatic zone is a region where has homogeneity in weather variables influencing crop growth and yield. Agro-climatic zones was used to identify crop yield and limiting factors for crop growth, to regionalize optimal crop management recommendations, to compare yield trends, to determine crop suitability, and to analyze impacts of climate change on agriculture (Gallup and Sachs, 2000; Seppelt, 2000; Caldiz *et al*., 2002; Fischer *et al*., 2005; Geerts *et al*., 2006; Williams *et al.,* 2008; Araya *et al*., 2010). In South Korea, agro-climatic zones for rice crop were classified into 19 zones using air temperature, precipitation, sunshine hours, and climatic productivity index (Choi and Yun, 1989). The zones have been used to develop safety cultivation criteria for rice crop and assess rice productivity and green-house gas emission, among others (Shim *et al*., 2013). However, there are only a few studies on water resources in the rice paddy field in Korea according to agro-climatic zones. Therefore, in this study, annual ET_0 was estimated for the agro-climatic zones for rice crops in Korea using Penman-Montheith method and annual ET_0 trends from 1980 to 2015 which were analyzed using the Mann-Kendall test.

II. Data and Methods

2.1. Meteorological data

Meteorological data from 61 weather stations provided by the Korean Meteorological Administration (KMA) were used in the study. Daily observation of mean, maximum, and minimum air temperature (℃), precipitation (mm), sunshine duration (hr), relative humidity (%) and daily mean wind speed (m/s) from 1981 to 2015 was used to calculate ET_0 of each weather station wherein values were averaged by agro-climatic zone. The location of these weather stations and agro-climatic zones are shown in Figure 1.

2.2. Analysis

The daily ET_0 was calculated by using the FAO-56 Penman-Monteith method (Allen *et al*., 1998).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}\mu(e_s - e_a)}{\Delta + \gamma(1+0.34\mu)} \quad \text{(Eq. 1)}$$

where, R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean air temperature (℃), u is the wind speed (m/s), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope vapor pressure curve (kPa/°C), and γ is the psychrometric constant (kPa/℃).

Student's t-test was used to assess the statistical significance of the difference of ET_0 between 1980-1994 and 2001-2015. It was also utilized for testing the significance of a correlation coefficient between ET_0 and meteorological factors. The Mann-Kendall test (Mann, 1945; Kendall, 1948) was used to detect a trend in ET_0.

III. Results and Discussion

Figure 2 represents the spatial distribution of average annual ET_0 across the agro-climatic zone for rice paddy field in South Korea. The average of annual ET_0 from 1980 to 2015 is 1334.1±33.89 mm. It shows that the ET_0 is the highest at the South Eastern Coastal Zone (Zone 19: 1444.4±39.52mm), followed by the Southern Coastal Zone (Zone 16: 1435.5±42.69. mm), then the North Eastern Coastal Zone (Zone 17: 1401.1±39.43.00 mm) and lastly, the Taebaek Alpine Zone (Zone 1: 1201.9±40.62 mm). The annual ET_0 in the mountain zones are lower than those of the plain zones due to lower mean temperature (6.6℃) and higher relative humidity (73%), which is the same as the result of the study of Gao *et al.* in 2017.

Figure 3 shows box plot representing maximum (upper whisker), 75th percentile (top of the box), median (line through the box), 25th percentile (bottom of the box), minimum (lower whisker) values of annual ET_0. These box plots indicate that annual ET_0 varies with a range of 1251.9 to 1400.0 mm for overall agro-climatic zones during 36 years. The median behaves similarly to the average shown in Fig. 2, that is the highest annual ET_0 at the South Eastern Coastal Zone (Zone 19: 1445.9mm) and the lowest annual ET_0 at the Taebaek Alpine Zone (Zone 1: 1210.7 mm). Variability, defined by a difference between maximum and minimum values (standard

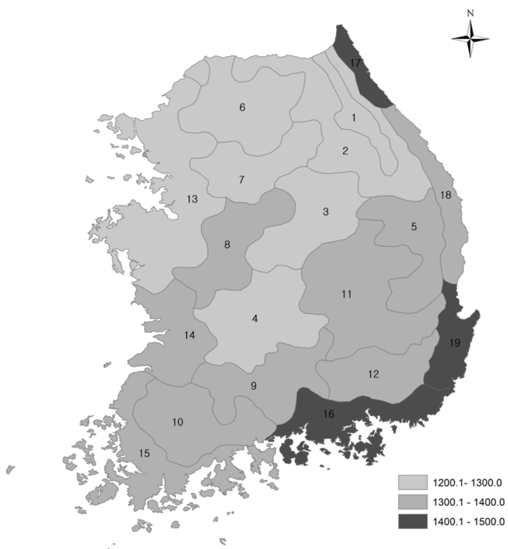

Fig. 2. Spatial distribution of the annual ET_0 averaged over the 36 years (1980-2015) in South Korea.

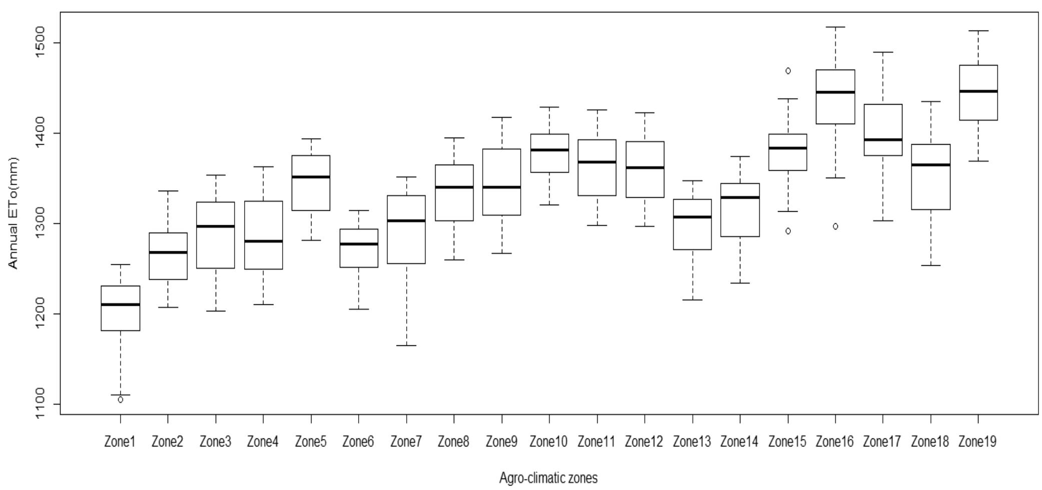

Fig. 3. Box plot of the annual ET_0 in South Korea for the 36 years (1980-2015).

Table 1. Meteorological factors averaged over the 36 years (1980-2015) over Korean agro-climatic zones

Agro-climatic Zones	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Mean Temp.	6.6	10.2	11.1	11.2	11.6	11.4	11.5	12.4	12.5	13.4	12.6	13.1	12.0	12.8	13.8	14.4	12.7	12.7	14.2
Max Temp	11.5	16.9	17.6	18.0	17.4	17.5	17.6	18.3	19.0	19.2	19.0	19.7	17.0	18.2	18.7	18.9	16.8	17.6	19.0
Min Temp	2.0	4.6	5.6	5.5	6.3	6.1	6.1	7.3	7.0	8.2	7.0	7.5	7.5	8.2	9.5	10.7	8.8	8.3	10.1
Prec.	1898	1335	1255	1352	1246	1668	1357	1332	1393	1448	1054	1339	1300	1279	1369	1651	1433	1096	1215
Sunhine Duration	2195	2162	2339	2279	2335	2187	2119	2222	2259	2116	2243	2254	2286	2286	2232	2323	2118	2460	2209
Relative Humidity	73	70	71	73	67	71	68	69	70	71	66	69	70	73	72	66	64	67	64
Wind Speeed	4.3	1.4	1.3	1.3	2.2	1.3	1.2	1.6	1.3	1.7	1.8	1.5	2.1	2.1	2.8	2.7	2.7	3.1	2.5

deviation), in annual ET_0 is the highest at the coastal zone 16 (Zone 18), while it is the lowest at inland zone 6 (Zone 6). It may be associated with relatively invariant climate variables of Zone 6 where relative humidity (2.6%) and wind speed (0.1m/s) have the lower standard deviation compared to the other zones (not shown). In Zone 15, its minimum (1291.8mm in 1980) and maximum (1468.8mm in 1998) annual ET_0 are considered as extreme values. The years in which the extreme annual ET_0 occurred are the same as the years in which abnormal temperature (12.7℃ in 1980, 14.7℃ in 1998) appeared.

Table 1 displays meteorological factors averaged over the 36 years (1980-2015) over Korean agro-climatic zones. It shows that the mean air temperature is the highest at the Southern Coastal Zone (Zone 16: 14.4℃), followed by the South Eastern Coastal Zone (Zone 19: 14.2℃), compared to the others. These two areas also have lower relative humidity (Zone 16: 66%, Zone 19: 64%) than the others. It infers these zones have relatively warm and dry climate which are favorable conditions for enhancement of ET_0 (Baldocchi *et al*., 2016). This result is similar to the Jung *et al*. (2014) revealed that the average annual air temperature in the South Eastern Coastal Zone was higher than in other agro-climatic zones.

Figure 4 displays the temporal changes in the average of annual ET_0 in South Korea from 1980 to 2015 on yearly basis. It shows a steady increase with a significant positive trend ($z=5.789$, $p<0.01$) of 2.81 ± 0.65 mm/yr for the whole study area. The

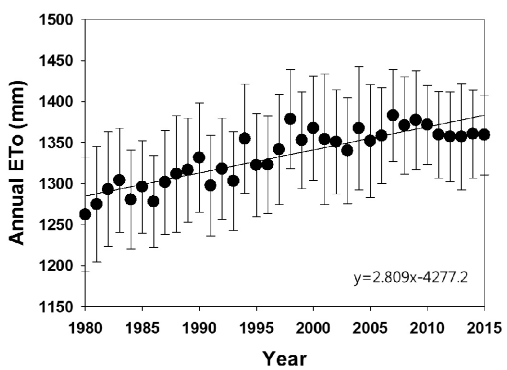

Fig. 4. Change in annual ET_0 averaged over all agro-climatic zones from 1980 to 2015 in South Korea.

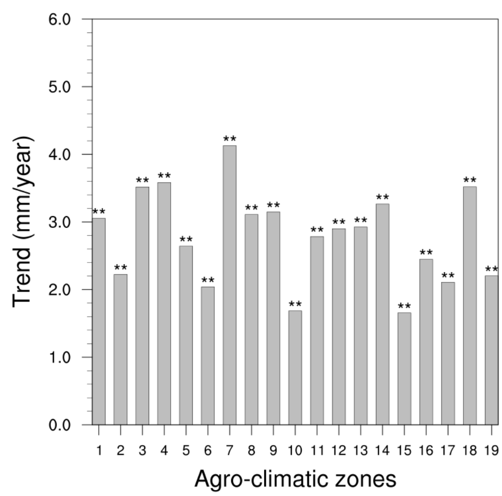

Fig. 5. Trend of annual ET_0 at each agro-climatic zone from 1980 to 2015 in South Korea. Asterisks indicate 99% confidence level.

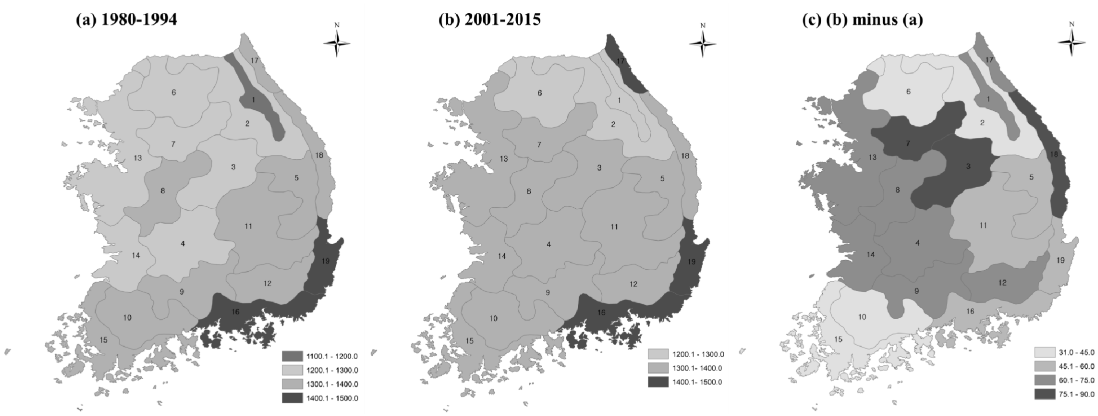

Fig. 6. Spatial distributions of annual ET_0 and a difference value between 1980-1994 and 2001-2015.

annual ET_0 of all agro-climatic zones are significantly increased over time. The change rates of those are different among agro-climatic zones, while the increase trends are statistically significant at all zones (Fig. 5). The change rate of the annual ET_0 is the highest in the Central Inland Zone (Zone 7) with 4.13 mm/yr, followed by the Noryeong Sobaek Mountainous Zone (Zone 4) with 3.58 mm/yr and the Eastern Coastal Zone (Zone 18) with 3.52 mm/yr, while that is the lowest in the Honam Inland Zone (Zone 10) with 1.68 mm/yr. As Korean statistical information service announced in 2018, Jeollanam-do (819,207 ton), Chungcheonname-do (743,080 ton) and Jeollabck-do (670,097 ton) provinces are the nation's largest producer of a food crop. These major production regions located at the Western Coastal and Central Zones (Zones 13-15) and the Honam Inland Zone (Zone 10) have been experiencing lesser transformation in the annual ET_0 compared to the other regions.

Figure 6 shows the spatial distributions of the annual ET_0 and the difference between 1980-1994 and 2001-2015. The South Eastern Coastal Zone (Zone 19) and the Taebaek Alpine Zone (Zone 1) have the highest and the lowest annual ET_0, respectively, for both periods due to their geophysical features. Over the recent 15 years (2001-2015), the annual ET_0 averaged over all zones increased by approximately 60 mm with 99% confidence level compared to the period 1980-1994. The annual ET_0 has significantly changed over all agro-climatic zones, especially around the Central Inland (7) and the Central Eastern Coastal (18) Zones.

Studies of Domenici *et al*. (2011), Liu *et al*. (2012), and Wang and Wang (2012) also reported an increasing trend of ET_0 in Southern Italy, China (1993-2007), and Loess area in China (last 50 years), respectively. However, Gao *et al*. (2006) found that ET_0 had a decreasing trend in China for a period 1956-2000. Also, Irmak *et al*. (2012) and Liu *et al*. (2016) found that ET_0 slightly decreased in the Platte river basin, the USA between 1960 and 2010, and increased from northeast to southwest in annual scale. The reason for the ET_0 change across different regions of the world has been studied. Climate change is thought to be the dominant factor. However, the effect of climatic factors on ET_0 is different according to regions. Jung *et al*. (2014) reported that the air temperature in the Central Inland Zone remarkably increased than it in the other agro-climatic zones between 1971 and 2000. On the other hand, Gao *et al*. (2017) reported that the solar radiation is the most dominant factor influencing annual ET_0 in the West Liao river basin in China, followed by maximum air temperature, relative humidity, and wind speed. Nabedzki *et al*. (2014) also insisted that the significant increase in ET_0 can be explained by the increasing air temperature and sunshine hours.

Because the primary meteorological factor is different in different regions, we estimate the relative contribution of climatic factors to the ET_0 change with the simple correlation analysis.

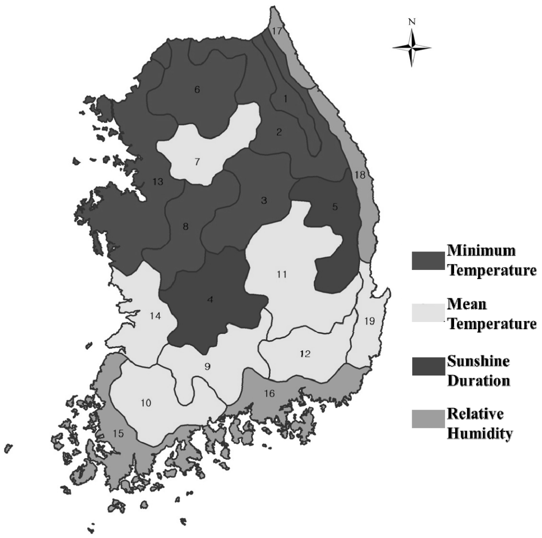

Fig. 7. Variables that have the highest correlation coefficient with annual ET_o.

In this context, we calculated the correlation coefficient between the annual ET_o and seven meteorological variables (mean temperature, maximum temperature, minimum temperature, precipitation, sunshine duration, relative humidity, and wind speed) at each zone for the period 1980-2015. We represent factors which have the highest correlation coefficient (above/below +/-0.7) with the annual ET_0 at each zone among seven meteorological variables (Fig. 7). These meteorological factors depicted in Fig. 7 are significantly correlated with the annual ET_0 with 95% confidence level. The high latitude places and the mountainous areas (e.g., the Taebaek Alpine Zone and the Semi-Alpine Zone, the Northern Central Inland Zone) are more influenced by the minimum temperature, while the low latitude regions (e.g., the Noryeong Eastern & Western Inland Zones and the Yeongnam Basin Zone) are more affected by the mean temperature. The inter-annual variations of annual ET_0 over southern and eastern coastal areas (e.g., the South Western Coastal Zone and the North Eastern Coastal Zone) are mostly related to the relative humidity. The annual ET_0 over inland mountainous regions located in the low latitude (i.e., the Noryeong Sobaek Mountainous Zone and the Yeongnam Inland Mountainous Zone) have a higher correlation with the sunshine duration rather than the others. Our study reveals that meteorological variables, mostly related to temporal variation of the annual ET_0, vary in different zones.

IV. Conclusions

Spatial and temporal analyses of reference evapotranspiration (ET_0) were conducted for the agro-climatic zones of South Korea. The results showed that the annual mean ET_0 in Korea was 1334.1±33.89 mm, and increased 2.8 mm/yr from 1980 to 2015. In the spatial distribution, the annual ET_0 in the mountains were lower than those of the plain zones, especially that of the South Eastern Zone and the Coastal Zone. The increasing trend of the annual ET_0 was the highest in the Central Inland Zone with 4.13 mm/yr, while that was the lowest in the Honam Inland Zone with 1.68 mm/yr. Over the recent 15 years (2001-2015), the annual ET_0 averaged over all zones increased by approximately 60 mm with 99% confidence level compared to the period 1980-1994. Meteorological factors, highly related to the yearly variation of the annual ET_0 in Korean agro-climatic zones are also investigated on the basis of the correlation coefficient. Four factors (the mean temperature, the minimum temperature, the sunshine duration, and the relative humidity) are well related to the inter-annual variability of annual ET_0. This study demonstrates that South Korea is experiencing a significant change of the annual ET_0 at all ago-climatic zones, and it is closely related to the variability of meteorological factors. The results will aid better understanding the variations of spatial and temporal ET_0, which can ultimately help improvements in the efficient use of water resources and agricultural planning over agro-climatic zones of South Korea.

적 요

본 연구는 1980년부터 2015년까지 논 농업기후지대에 대한 연 기준 증발산량(annual reference evapotranspiration, ET_0)을 추정하고 분석하였다. 기상청에서 수집한 61개 지점의 기상자료에 Penman-Monteith 방법을 적용하여 일별 기준 증발산량을 계산하였다. 1980년부터 2015년 동안의 연 기준 증발산량은 평균 1334.1±33.89 mm 이였으며, 해안 지대에서 가장 높게 나타났다. 기준 증발산량은 전체 지대에 대해서 약 2.81 mm/yr의 추세로 증가하였다. 하지만 변화율은 농업기후지대별로 다르게 나타났다. 특히 중부지대와 동부 해안 지대에서 연 기준 증발산량은 가장 크게 증가하였다. 상관계수 분석에 의하면, 연 기준 증발산량의 연 변화는 네가지 기후 요소(평균, 최저 기온, 일조시간, 상대습도)와 가장 크게 연관이 있었다. 이 연구는 36년 동안 전체 한국 농업지대에서 연 기준 증발산량의 변화를 겪고 있다는 것을 보여주고 있다. 온난화와 관련된 장기간의 연기준 온도의 변화와 공간적 패턴을 이해하는 것은 각 농업기후지대별 수자원 및 작물 관리를 효율적으로 할 수 있도록 도와줄 것으로 생각된다.

Acknowledgements

This study was carried out with the support of "Research Program for Agricultural Science & Technology Development (Project No. PJ01185802)", National Institute of Agricultural Sciences, Rural Development Administration, Republic of Korea.

REFERENCES

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith, 1998: Crop evapotranspiration. Guidelines for computing crop water requirements. FAO, Rome, Irrig. Drain. Paper 56, 2-15.

Araya, A., S. D. Keesstra, and L. Stroosnijder, 2010: A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. *Agricultural Forest Meteorol*ogy **150**(7-8), 1057-1064.

Baldocchi, D., S. Knox, I. Dronova, J. Verfaillie, P. Oikawa, C. Sturtevant, J. H. Matthes, M. Detto, 2016: The impact of expanding flooded land area on the annual evaporation of rice. *Agricultural and Forest Meteorology* **223**, 181-193.

Caldiz, D. O., A. J. Haverkort, and P. C. Struik, 2002: Analysis of a complex crop production system in interdependent agro-ecological zones: a methodological approach for potatoes in Argentina. *Agricultural Systems* **73**(3), 297-311.

Choi, D. H., and S. H. Yun, 1989: Agroclimatic zone and characters of the area subject to climatic disaster in Korea. *Korean Journal Crop Sci*ence **34**, 13-33. (in Korean with English abstract)

Fischer, G., M. Shah, and F. N. Tubiello, H. van Velhuizen, 2005: Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990−2080. *Philosophical Transactions Royal Society B* **360**, 2067-2083.

Gallup, J. L., and J. D. Sachs, 2000: Agriculture, climate, and technology: why are the tropics falling behind? *American Journal of Agricultural Economics* **82**, 731-737.

Gao, G., D. Chen, G. Ren, Y. Chen, and Y.M. Liao, 2006: Spatial and temporal variations and controlling factors of potential evapotranspiration in China:1956−2000. *Journal of Geographical Sciences* **16** (1), 3−12.

Gao, Z., J. He, K. Dong, and X. Li, 2017: Trends in reference evapotranspiration and their causative factors in the West Liao River basin, China. *Agricultural Forest Meteorol*ogy **232**, 106-117.

Geerts, S., D. Raes, M. Garcia, C. Del Castillo, and W. Buytaert, 2006: Agro-climatic suitability mapping for crop production in the Bolivian Altiplano: a case study for quinoa. *Agricultural Forest Meteorology* **139**, 399-412.

Huo, Z., X. Dai, S. Feng, S. Kang, and G. Huang, 2013: Effect of climate change on reference evapotranspiration and aridity index in arid region of China. *Journal of Hydrology* **492**, 24−34.

Ikawa, H., K. Ono, M. Mano, and K. Kobayashi, 2017: Evapotranspiration in a rice paddy field over 13 crop years. *Journal of Agricultural Meteorology* **73**(3), 109-118.

Irmak, S., I. Kabenge, K. E. Skaggs, and D. Mutiibwa, 2012: Trend and magnitude of changes in climate variables and reference evapotranspiration over 116−yr period in the Platte River Basin, Central Nebraska−USA. *Journal of Hydrology* **420-421**, 228−244.

Jhajharia, D., Y. Dinpashoh, E. Kahya, V. P. Singh, and A. Fakheri−Fard, 2012: Trends in reference evapotranspiration in the humid region of northeast India. *Hydrological Processes* **26**, 421−435.

Jhajharia, D., Y. Dinpashoh, E. Kahya, R. R. Choudhary, and V. P. Singh, 2014: Trends in temperature over Godavari River basin in Southern Peninsular India. *International Journal of Climatology* **34**, 1369−1384.

Jung, M.-P., K. M. Shim, Y. Kim, S. C. Kim, and K. H. So, 2014: Changing trends of climatic variables of agro-climatic zones of rice in South Korea. *Climate Change Research* **5**(1), 13-19. (in Korean with English abstract)

Kendall, M. G., 1948: Rank correlation methods. Oxford, England, Griffin.

Komatsu, H., T. Kume, and K. Otsuki, 2008: The effect of converting a native broad leaved forest to a coniferous plantation forest on annual water yield: a paired−catchment study in northern *Japan. Forest Ecology and Management* **255**(3-4), 880−886.

Liu, Q., Z. Yang, B. Cui, and T. Sun, 2010: The temporal trends of reference evapotranspiration and its sensitivity to key meteorological variables in the Yellow River Basin, China. *Hydrological Process* **24**(15), 2171−2181.

Liu, C., D. Zhang, X. Liu, and C. Zhao, 2012: Spatial and temporal change in the potential evapotranspiration sensitivity to meteorological factors in China (1960−2007). *Journal of Geographical Science*s **22**(1), 3−14.

Liu, T., L. Li, J. Lai, C. Liu, and W. Zhuang, 2016: Reference evapotranspiration change and its sensitivity to climate variables in southwest China. *Theoretical and Applied Climatol*ogy **125**, 499-508.

Mann, H. B., 1945: Nonparametric tests against trend. *Econometrica* **13**, 245−259.

Nabedzki, L., B. Bak, and K. Smarzynska, 2014: Spatio-temporal variability and trends of Penman-Monteith reference evapotranspiration (FAO-56) in 1971-2010 under climatic conditions of Poland. *Polish Journal of Environmental Studies* **23**, 2083-2091.

Palumbo, A. D., D. Vitale, P. Campi, and M. Mastrorilli, 2011: Time trend in reference evapotranspiration: analysis of a long series of agrometeorological measurements in Southern Italy. *Irrigation Drainage System* **25**(4), 395−411.

Sabziparvar, A. A., H. Tabari, A. Aeini, and M. Ghafouri, 2010: Evaluation of class a pan coefficient models for estimation of reference crop evapotranspiration in cold-semi arid and warm arid climates. *Water Resources Management* **24**(5), 909−920.

Seppelt, R., 2000: Regionalised optimum control problems for agroecosystem management. *Ecological Modelling*. **131**, 121-132.

Shim, K. M., Y. Kim, M.-P. Jung, S. C. Kim, S. H. Min, and K. H. So, 2013: Agro-Climatic zonal characteristics of the frequency of abnormal air temperature occurrence in South Korea. *Climate Change Research* **4**, 189-199.

Thomas, A., 2000: Spatial and temporal characteristics of potential evapotranspiration trends over China. *A Journal of the Royal Meteorological Society* **20**(4), 381−396.

Tabari, H., A. Aeini, P. H. Talaee, and B. S. Some'e, 2012: Spatial distribution and temporal variation of reference evapotranspiration in arid and semiarid regions of Iran. *Hydrological Processes* **26**, 500−512.

Wang, S., and Q. J. Wang, 2012: Analysis of variation of climate and potential evapotranspiration and its influencing factors in the Loess area in last 50 years. *Agricultural Research Arid Area* **30**(1), 270−278.

Williams, C. L., M. Liebman, J. W. Edwards, D. E. James, J. W. Singer, R. Arritt, and D. Herzmann, 2008: Patterns of regional yield stability in association with regional environmental characteristics. *Crop Science* **48**, 1545-1559.

Yoshimoto, M., M. Fukuoka, T. Hasegawa, and M. Utsumi, 2011: Integrated micrometeorology model for panicle and canopy temperature (IM2PACT) for rice heat stress studies under climate change. *Journal of Agricultural Meteorology* **67**, 233-247.

Zuo, H. C., D. L. Li, Y. Q. Hu, Y. Bao, and S. H. Lv, 2005: Relationship of the climate change and pan evaporation in the recent 40 years in China. *Chinese Science Bulletin* **50**(11), 1125−1130.