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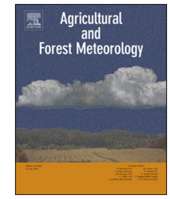


# Reference evapotranspiration changes in Slovenia, Europe

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A B S T R A C T

Evapotranspiration is an important element of the water cycle and possible trends in the evapotranspiration can, among others, influence on the water management and agricultural production. Since actual evapotranspiration values are rare and difficult to estimate, reference evapotranspiration was examined in order to document changes in the climatic conditions that affect evapotranspiration. The daily reference evapotranspiration data calculated using the Penman-Monteith method from 18 meteorological stations located in three different climate types in Slovenia was examined in this study. 55 years of data from 1961 until 2016 was analysed. The Mann-Kendall test was applied in order to detect trends in different samples that were defined based on the daily reference evapotranspiration data. Relationship between the evapotranspiration and influencing factors was also investigated using the generalized boosted regression trees model. The calculated trends for different samples are mostly increasing and statistically significant while no consistent trend could be detected for all 18 stations. The maximum increase in the daily reference evapotranspiration for the observed period was 0.5 mm and the maximum decrease −0.4 mm. Moreover, upward trend was detected for two mountain stations and downward for one sub-Mediterranean station. No uniform trend could be found for the stations located in the temperate continental climate. Furthermore, generalized boosted regression trees model indicated that solar radiation has the largest impact on the reference evapotranspiration values, generally followed by air temperature, saturation vapour pressure deficit and wind speed.

## 1. Introduction

Since global surface mean temperature around the world increased significantly in the last decades (Easterling et al., 1997; Jones et al., 1999; IPCC, 2014) one can expect also changes in other components of the hydrological cycle and its processes (Barnett et al., 2005; McVicar et al., 2012). Warming climate is expected to have significant influence on the water storage and consequently water availability around the world. However, observed changes in individual hydrological cycle components differ between regions and no uniform pattern can be found around the world (e.g., Douglas et al., 2000; Liu et al., 2008; Hall et al., 2014; Leeuw et al;, 2016; Plavšić et al., 2016; Svoboda et al., 2016; Šraj et al., 2016a, b; Blöschl et al., 2017; Wrzesiński and Sobkowiak, 2017).

Evapotranspiration can be regarded as one of the most important factors in order to indicate climate change at the catchment scale since it influences both on surface runoff and water storage in the catchment (e.g., Yao et al., 2005; Cannarozzo et al., 2006; Liu et al., 2008; Yang et al., 2011). If evapotranspiration rates are very high and near precipitation value, this can cause water shortage for crops (Łabędzki et al., 2014). Furthermore, increase in evapotranspiration leads to lower amount of available water for human activities and natural processes. Numerous studies have already been carried out in order to examine the trends in the reference evapotranspiration ($ET_0$) (e.g., Papaioannou et al., 2011; Vicente-Serrano et al., 2014; Azizzadeh and Javan, 2015; Dadaser-Celik et al., 2016), which defines atmospheric evaporative demand of the reference crop estimated based on climatic variables. It was found that trends in $ET_0$ vary significantly with climatic conditions and regions (Rim, 2009; Wang et al., 2014). For example, the study in the Northwest part of Iran indicated that the majority of 20 synoptic stations have an increasing trend on monthly, seasonal and annual scale over the 22-year time period (1986–2007) (Azizzadeh and Javan, 2015). Furthermore, the results of some studies showed the decreasing water availability in the Mediterranean region in the recent decades based on the observational datasets (Chaouche et al., 2010; Espadafor et al., 2011; Papaioannou et al., 2011; Palumbo et al., 2011; Vergni and Todisco, 2011; Kitsara et al., 2013; Vicente-Serrano et al., 2014). Moreover, most of the analysed stations in Spain have increasing and statistically significant trends in the $ET_0$ from 1961 to 2011, which could be the result of the decrease in the relative humidity and the increase in the maximum air temperature (Vicente-Serrano et al., 2014). Additionally, Thepprasit et al. (2009) showed the increasing

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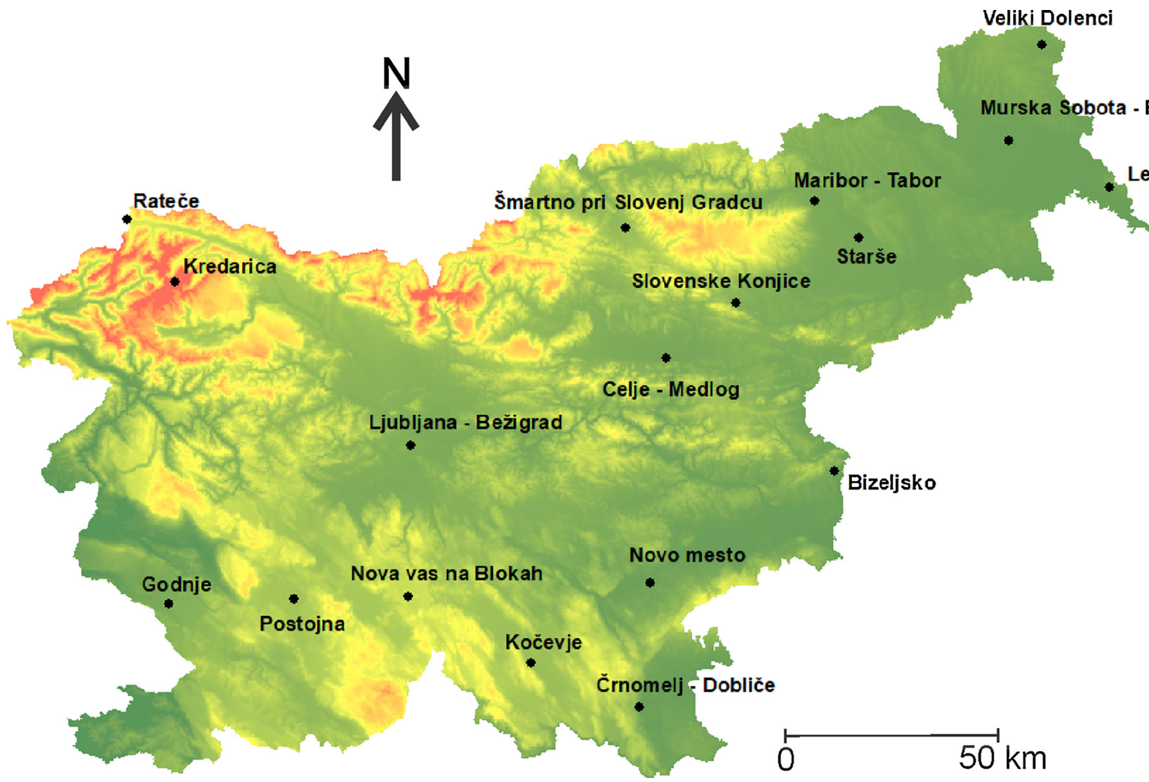


**Fig. 1.** Location of 18 analyzed meteorological stations on the map of Slovenia.

trend in the air temperature and the relative humidity and the decreasing one in the wind speed in the Upper Chao Phraya River Basin in Thailand. Also at global scale, a general increase in the land surface evaporation can be detected despite the decreasing trend in the pan evaporation rates (e.g., Brutsaert and Parlange, 1998; Brutsaert, 2006). However, some studies have detected decreasing surface evaporation trends (e.g., Shan et al., 2017), including those in the Yellow River Basin and some other regions in China (Ji et al., 2012; Xing et al., 2016). Moreover, generally the atmospheric evaporative demand is mostly decreasing (McVicar et al., 2012).

Evapotranspiration is a very complex process that depends on several climatic variables, crop characteristics and other environmental aspects (Allen et al., 1998). According to the definition of the reference evapotranspiration $ET_0$ the last two could be omitted, so the only factors affecting $ET_0$ are climatic variables. Hence, there are some studies focused on the relationship between reference evapotranspiration and influencing climatic variables. However, the results indicating that the significance of the climatic variables influencing reference evapotranspiration varies from region to region (e.g., Yang et al., 2011; Cesar and Šraj, 2012; Wang et al., 2014; Gao et al., 2017; Duethmann and Blöschl, 2018). Cesar and Šraj (2012) made an overview of the influencing factors and methods for calculation the reference evapotranspiration rates. The sensitivity analyses of individual climatic factors have shown that evapotranspiration rates at the location of four meteorological stations in Slovenia (Kredarica, Ljubljana, Murska Sobota, Portorož) depended mostly on solar radiation, followed by air temperature and relative humidity, whereas wind speed demonstrated the lowest impact (Cesar and Šraj, 2012). Duethmann and Blöschl (2018) analysed changes in the annual reference evapotranspiration over 156 catchments in Austria and reported increased values of $ET_0$ by 2.8 ± 0.7% per decade (averaged over all catchments) during 1977–2014. They also demonstrated that the increase was largely driven by increasing net radiation (76%) and increasing air temperature (19%). On the other hand, Yang et al. (2011) reported the most sensitive parameter in the $ET_0$ estimation of the Yellow River Basin, China, was relative humidity, followed by air temperature, solar radiation and wind speed (Yang et al., 2011). Furthermore, Wang et al. (2014) studied climate change effects on the reference evapotranspiration in the Hetao Irrigation District in northern China. They documented $ET_0$ is the most sensitive to the mean daily air temperature, followed by wind speed and relative humidity.

Since evapotranspiration is an important process of the water cycle and because increase in the evapotranspiration could lead to the surface and subsurface runoff decrease, groundwater storage decrease and consequently to the water management issue, the main aim of this study was to evaluate potential temporal changes of $ET_0$ for different climate types in Slovenia. The $ET_0$ series were calculated using the standard FAO Penman-Monteith equation in order to examine changes in $ET_0$ series and at the same time effects of changes in atmospheric conditions and their contributions to the trend of $ET_0$. Four different samples were defined based on the daily $ET_0$ data, namely daily $ET_0$, monthly maxima, annual sum and annual maxima of the daily $ET_0$. The idea behind investigation of different samples was to evaluate potential changes at different temporal scales. For example, climate change or variability could lead to more hot days in summer and at the same time to more cold days in winter times. If the increase in the summer $ET_0$ is similar to the decrease of the $ET_0$ in winter it is possible that no significant trend could be detected on annual scale. However, higher summer $ET_0$ would result in increasing monthly maxima trends. Moreover, increasing monthly maxima could have significant negative impact on the agricultural production. Thus, Mann-Kendall test was applied to the 55-year period (1961–2016) of data of all four samples for 18 meteorological stations located in Slovenia (Europe) in different climatic conditions. Moreover, the relative contribution of the radiative ($ET_{0R}$) and aerodynamic ($ET_{0A}$) components was also examined. Additionally, analyses of four influential variables, namely average daily air temperature ($T$), daily global solar radiation ($SR$), daily saturation vapour pressure deficit ($e_s$-$e_a$) and daily wind speed ($WS$) on the $ET_0$ were performed using generalized boosted regression trees model.