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Thornthwaite's approach for assessing aridity changes during the last seven decades in the urban environment of Heraklion-Crete in Greece

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Abstract Changes in aridity, especially to more arid classes, can have a strong impact on vegetation development in urban environments affecting also the inhabitants' health and quality of life. In this work, water related parameters (i.e. Potential evapotranspiration PET, water deficit D and surplus S) and aridity index AI were examined according to Thornthwaite's approach, in the city of Heraklion – Crete in Greece during the period 1955-2017. The decadal analysis of seven decades (1950s to 2010s) indicates that S remains negligible, however PET and D have increased values varying from 938mm in 1980s to 1007mm in 2010s for PET and from 396mm in 1960s to 568mm in 2010s for D, whereas precipitation has decreased presenting maximum in 1960s (579mm) and minimum in 2010s (422mm). Therefore, the recent decade (2010s) is more arid compared to the past, displaying the lowest AI value (0.42). During the previous decades, AI was much higher with values between 0.60 in 1960s and 0.44 in 1990s, indicating that the region was at the edge of the threshold (0.50) for changing aridity zone from sub-humid (SH) to semi-arid (SA), according to UNEP's classification.

Keywords: Climate, Aridity, Crete, Thornthwaite, UNEP

1. Introduction

Mediterranean is considered as climate change (Diffenbaugh and Giorgi 2012) and biodiversity hotspot (Myers et al. 2000; Solomou at al. 2019). Especially the eastern part of the basin is anticipated to face even more harsh conditions in the future (Tanarhte et al. 2012).

In Greece, Tsiros et al. (2020) analyzed data for the last century from 91 meteorological stations and identified climate shifts to more arid conditions for many Greek areas. Warming trends are also identified for maximum temperatures in the south part of the Greek peninsula in mountainous areas (Proutsos et al. 2010), indicating that extreme events have already affected the high altitudinal ecosystems of the country. Additionally, Tigkas (2008) reports long lasting droughts for many regions of Greece. Such climatic variations can have a significant effect on plant's growth rates (Proutsos and Tigkas 2020).

Heraklion, is a city of Crete, an island located at the southern part of Greece and Europe. The broader area is characterized by a high biodiversity, which is the result of local climate and its variations.

In order to preserve and utilize the unique Cretan flora and fauna, a continuous monitoring of the local climate conditions is necessary. The present work is based on the work of Tsiros et al. (2020), who studied the changes in aridity and water related parameters for the Greek peninsula (including Heraklion) in three climatic periods (1900-1930, 1930-1960, 1960-1997). In this work we study in more detail the recent decadal changes from 1950s to nowadays, of the aridity and water related parameters, specifically in Heraklion, through the bioclimatic water budget approach of Thornthwaite (1948), used also by Tsiros et al. (2020), in order to identify possible future impacts on the local environment and risks for the conservation of local forest and urban ecosystems.

2. Data and Analysis

The climate in Heraklion is Mediterranean type classified as sub-humid according to UNEP's (1992) climate zone classification system. According to Tsiros et al. (2020) the Aridity Index (Thornthwaite 1948) presented to decrease the recent years compared to the past from 0.56 in 1900-1930 to 0.52 in 1960-1997, indicating a shift to more arid climate zones. Additionally, the local climate is changing with more rapid rates during the last years, especially from 1985 and later (Proutsos et al. 2020) and significant positive trends of all temperature attributes (maximum, minimum, mean) were identified for the period 1955-2017 (Proutsos et al. 2019).

For the present study, long term monthly meteorological data of average air temperature T and precipitation P for the period 1955-2017 were used, obtained from the meteorological station of Heraklion, installed and operates by the Hellenic National Meteorological Service (35.34° N, 25.18° E, alt. 39m a.s.l.). The station is part of the WMO climatic network with ID: 16754.

The data were used in order to produce monthly estimates of potential evapotranspiration (PET) by employing

Thornthwaite's (1948) formula. In order to assess the aridity of the region and study its decadal changes, UNEP's (1992) Aridity Index (AI=P/PET) was used. According to UNEP's (1992) system five climatic classes are defined: hyper-arid HA (AI<0.05), arid A (AI=0.05-0.20), semi-arid SA (AI=0.20-0.50), sub-humid SH (AI=0.50-0.65) and humid H (SA>0.65), whereas Tsiros et al. (2020) identified three of them in the Greek peninsula (H, SH, SA). Additionally, Thornthwaite's water balance approach (Thornthwaite 1948; Thornthwaite and Mather 1955) was adopted in order to study the water availability for vegetation by the estimations of water related parameters i.e. monthly water deficit (D) and surplus (S). For more details concerning the Thornthwaite's water balance, reader can refer to Thornthwaite (1948, 1955), Thornthwaite and Mather (1955) and Thornthwaite et al. (1957).

3. Results

The application of Thornthwaite's water balance approach to the available monthly data of Heraklion is presented in Table 1 and graphically depicted in Figure 1. In general, the region is characterized by diminished precipitation P varying from 422 mm in the recent decade (2010s) to 579 mm in 1960s. However, the warming temperatures in the region result in high potential evapotranspiration PET rates ranging from 938mm in 1980s to 1007 in 2010s. These very high values are almost twice as large compared to precipitation. Very high values are also presented for the water deficit D mainly occurring during the hot and dry summer period. From 1950's these values remain high for all decades presenting a slight variation from 396 mm in 1960s to 568mm in 2010s. Finally, the water surplus S which refers to the winter water stored in the soil in order to support vegetation in spring and summer, is zero for all decades except from the 1960s when it presented a very low value of 4.3mm.

Table 1. Decadal values of the water related parameters (Precipitation P, potential evapotranspiration PET, water deficit D and water surplus S) for the city of Heraklion – Crete, based on Thornthwaite's water balance approach.

Decade	P(mm)	PET(mm)	D (mm)	S(mm)
1950	442	959	492	0
1960	579	970	396	4.3
1970	454	943	469	0
1980	483	938	451	0
1990	424	961	528	0
2000	490	979	490	0
2010	422	1007	568	0

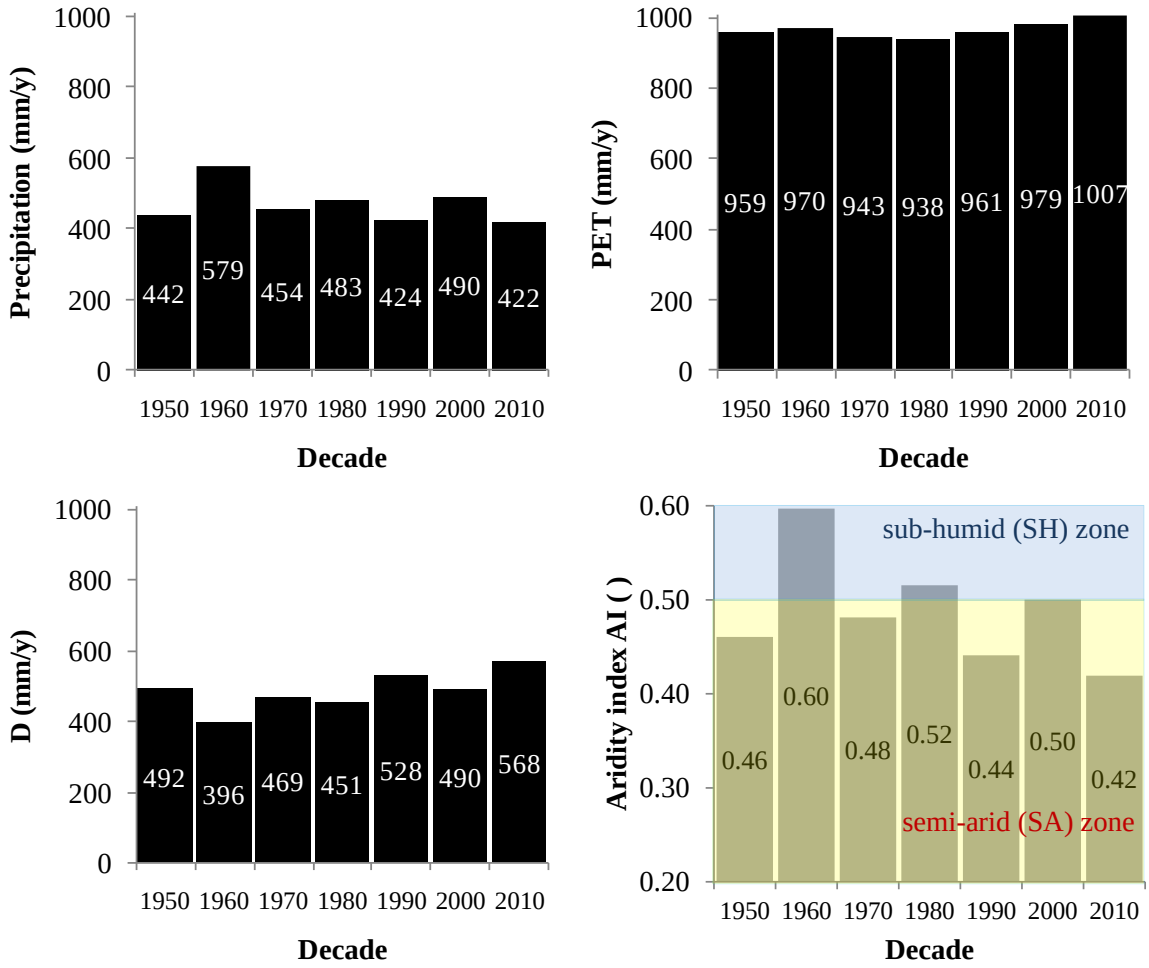

Figure 1. Graphical representation of the average decadal (1950s to 2010s) values of precipitation P, potential evapotranspiration PET, water deficit D, water surplus S and the Aridity index for the city of Heraklion Crete, based on Thornthwaite's water balance approach.

The Aridity Index (AI) in Heraklion also presents changes that underline the more rapid and harsh recent climate conditions compared to the past. The AI values are very close to the threshold between the semi-arid SA (AI=0.20-0.50) and sub-humid SH (AI=0.50-0.65) climate zones according to UNEP's (1992) classification system. Tsiros et al. (2020) categorized the region to the sub-humid SH climatic type by assessing data from the beginning of the century. However, the recent trends (from 1950s and after) appear to be more rapid (Proutsos et al. 2019, 2020).

The more detailed decadal analysis, presented in this work, indicates that in many decades since 1955 (1950s, 1970s, 1990s, 2010s) the local climate passed the threshold between sub-humid and semi-arid climate (AI=0.50). The lowest AI (0.42) is estimated for the recent decade (2010s), suggesting a very rapid decrease compared to the previous decade (2000s with AI=0.5) and implying also that the semi-arid climate is highly possible to persist in the future. This is also supported by the low AI value of 0.44 in 1990s in conjunction with the significant positive temperature trends for the 1955-2017 period and the 1955-1985, 1985-2017 sub-periods, identified in the studies by Proutsos et al. (2019, 2020) for the same region, that can further enhance PET and further reduce the values of AI.

4. Conclusions

From the above described patterns is indicated that natural vegetation in Heraklion is under strong water stress. Additionally, these hard conditions appear to shift to even stronger environmental stresses, since in the recent decade (2010s) water requirements (PET) are maximized and on the other hand available precipitation water is further decreased. This is crucial for the sustainability of the unique vegetation in the region of Heraklion but also for the whole island of Crete and introduces an urgent need for undertaking initiatives and implementing actions in order to preserve and utilize the local biodiversity and preserve the forest and urban ecosystems.

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