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Estimation of the Meteorological Forest Fire Risk in a Mountainous Region by Using Remote Air Temperature and Relative Humidity Data

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Abstract. The occurrence of forest fires is frequent phenomenon in Greece, especially during the warmest period of the year, the summer. Timely and reliable estimation of the meteorological risk for their onset is of crucial importance for their prevention. Thus, the purpose of our current work was firstly the estimation of the values of a suitable relevant index for Greece, meteorological forest fire risk index ($MK_{s,t}$), derived from actual air temperature (T) and relative humidity data (RH) as well as from regressed T and RH, in a mountainous region (MR) of Nafpaktia, Greece, for the most dangerous period of the year (July-August) and day (11:00 h -16:00 h), for five successive years (2006-2010) and secondly the comparison of the two ways of $MK_{s,t}$ values estimation (from actual and regressed T and RH), based on $MK_{s,t}$ classes. Regressed T and RH data were estimated with the aid of simple linear regression models from T and RH data, respectively, of an urban region, 175 Km away from MR, taking into account firstly the warmest (2007) and the coldest (2006) year of the examined year period. It was confirmed that $MK_{s,t}$ values (based on regressed T and RH data) coincided in their classification to the respective ones resulted from actual T and RH data, that is, there was absolute success (100%). Using simple linear regression lines and applying them to estimate separately T and RH at MR, for the most dangerous period of year and day concerning the whole examined year period, it was found that almost all the estimated $MK_{s,t}$ values coincided, regarding their classification, with those estimated from actual T and RH data (97% success), which was considered very satisfactory. Therefore, our research methodology contributes a new perspective to a reliable estimation of $MK_{s,t}$ from remote T and RH data using simple statistical models.

Introduction

Fire is one of the most destructive events in human, plant and animal life as well as a crucial factor for the degradation of various types of ecosystems like the Mediterranean ones [1]. More specifically, the negative impact of fires on people progress has a lot of extensions. For example, there are social implications (human and property loss) as well as environmental ones, concerning fire contribution to global climatic variability and overheating of our planet [2].

When a fire starts its harmful action, especially in areas where the human interference may be delayed or impossible, for a number of reasons, like inaccessible terrain or prohibitive weather conditions, the problem of burning may be enlarged very quickly. Finally, very bad consequences may take place, regarding humans, plant and animal material of the impacted area. It is undoubtedly better, if possible, the prevention of the fire than its fighting [3].

Therefore, various meteorological forest fire risk indices have been developed by numerous research teams to forecast the risk of fire occurrence and aid forest managers to take suitable preventive measures [4]. The most important fire risk indices, in which various meteorological variables are used as inputs, among others, have been reported [5] to be Angström index, Nesterov index [6, 7], Drouet and Sol Numerical Risk [8, 9], Forest Fire Danger Index [10-13], Canadian Fire

Weather Index [7, 14] and Portuguese fire risk index [15]. The meteorological data which are used for the estimation of the relevant indices must represent a reliable situation of the evaluated regions, that is, they must originate from meteorological stations located inside or nearby these regions [3]. However, several researchers have underlined the problem of lack of representative meteorological data from forest regions [16, 17] with Greece to be no exception.

In our present study, to overcome the aforementioned problem in Greece, which has suffered repeatedly from forest fires, with a peak during the late summer of the year 2007 [18], we followed an innovative approach. In particular, the purpose of the present work was firstly to estimate the values of an appropriate meteorological forest fire risk index in a mountainous region (MR) in Greece from meteorological data derived from relevant meteorological data of a remote urban region with the aid of simple statistical methods and secondly to compare the aforementioned index values originated from actual data and estimated data in terms of its classes.

As far as we know, there is no available or similar literature regarding the aforementioned approach. This lack created the need to conduct the present work, testing the hypothesis of obtaining accurate estimations of the studied index by remote data. The resulted information would be of great interest concerning the possible overcome of limitations of reliable meteorological data for the estimation of meteorological forest fire risk as mentioned above.

Materials and Methods

Study regions and measurement sites. Research was carried out in two regions; the first one was a MR of the municipality of Nafpaktia, Prefecture of Aitoloakarnania, western continental Greece. Mountainous Nafpaktia is characterized by diverse relief and many brooks which flow into the Evinos River and these, along with the existence of *Quercus* sp. L. (oak), *Abies cephalonica* L. (fir), *Fagus silvatica* L. (beech), *Platanus* sp. L. (plane), and *Castanea sativa* Mill. (chestnut) trees which are interchanged, offer a unique beauty [19] to the visitor who reaches the place for ecotourism and various recreational activities. The second region was a highly populated urban region of the municipality of Athens, capital of Greece, in the prefecture of Attica of southeast continental Greece.

There were two measurement sites; the first (S1) at MR (38^{o}44′04.4″ N, 21^{o}57′36.9″ E, alt. 821 m), near a riverbank of a tributary of Evinos River at the location Mandrini, and the second (S2) at Athens (37^{0}58΄55΄΄N, 23^{0}32΄14΄΄E, alt. 30 m), at the location Votanikos, about 175 Km away from S1 (Fig. 1).

Air temperature and relative humidity data collection and processing. Air temperature (T) and relative humidity (RH) were recorded continually every min by a sensor (SKH 2070, Skye Instruments Ltd, UK, accuracy ±0.2-0.5 °C and 2% RH) with a data logger (DL2, Delta-T Devices Ltd., UK) being placed in an automatic meteorological station (AMS). There was one AMS in each measurement site. From these recorded initial data the average T and RH were estimated, firstly, on an one-hour basis and, secondly, on an one-day basis. Then, from the T and RH averages on a daily basis, averages were estimated, on a month-basis, for five successive years (2006-2010). About every five months, the sensors were tested in situ against reference sensors, where no noticeable shift errors were observed for any of the installed sensors. The T and RH differences among the aforementioned sensors and the reference sensors were not higher than 0.1 °C and 3%, respectively, and were taken appropriately into account. The installed sensors were enclosed in appropriate shelters screened from precipitation and direct solar radiation and placed 1.5 m above ground surface.

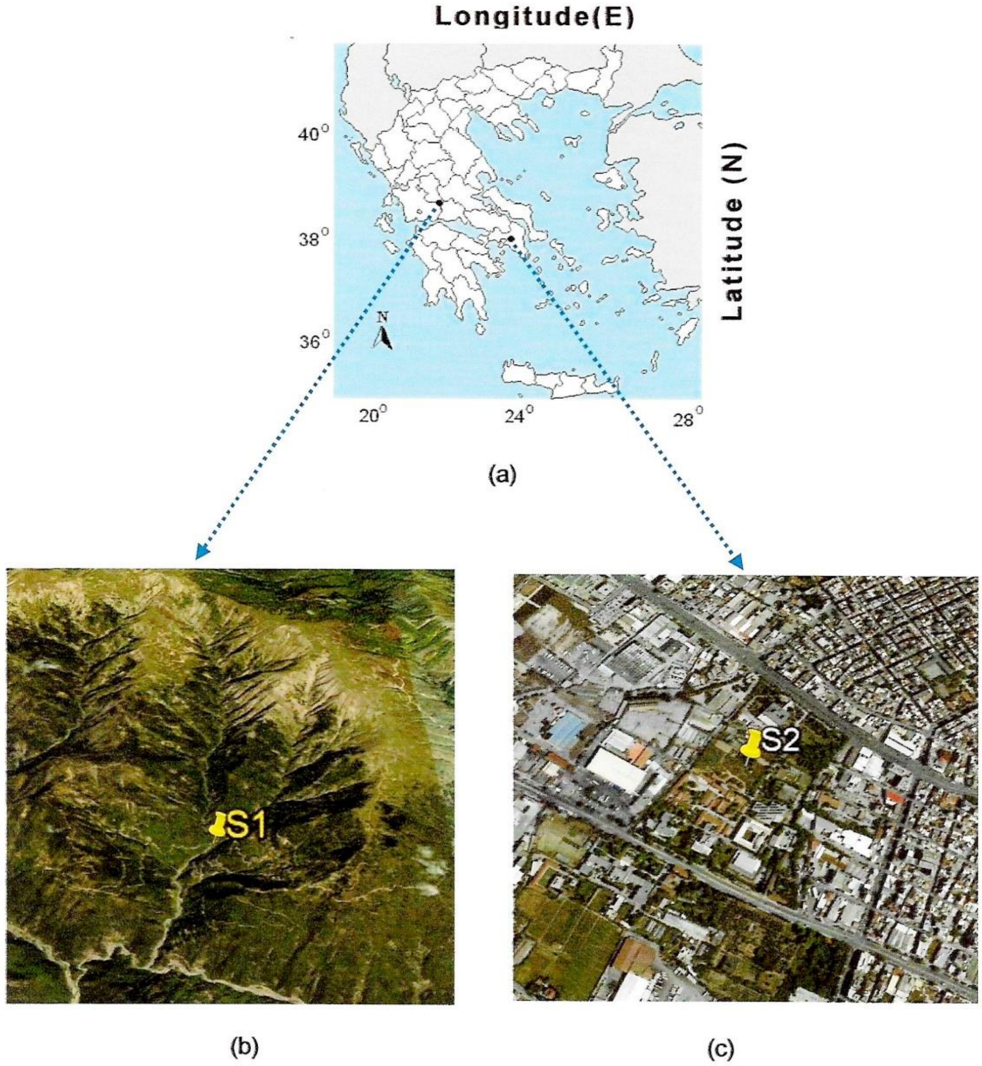

Figure 1. Study regions (circles with black color) of mountainous Nafpaktia and Athens, Greece (a) and measurement sites in (b) mountainous Nafpaktia (S1) and (c) Athens (S2), modified from [20]

Evaluation of meteorological forest fire risk. In our study, we selected to use a well-suited index for the conditions of Greece, regarding the estimation of meteorological forest fire risk at Mandrini, using T and RH data. Note that there are available data of both T and RH in the majority of the meteorological stations in our country [21]. The selected index, resulted from a modification of the Portuguese fire risk index, was calculated according to Eq.(1) [5]:

$$MK_{s,t} = T_{s,t} \cdot \left(T_{s,t} - \frac{237.3 \cdot \left(\log\left(\frac{RH_{s,t}}{100}\right) + \frac{7.5 \cdot T_{s,t}}{237.3 + T_{s,t}} \right)}{7.5 - \left(\log\left(\frac{RH_{s,t}}{100}\right) + \frac{7.5 \cdot T_{s,t}}{237.3 + T_{s,t}} \right)} \right), \tag{1}$$

where $MK_{s,t}$: Meteorological forest fire risk index at site s and time t, $T_{s,t}$: Air temperature (°C) at site s and time t and $RH_{s,t}$: Relative humidity (%) at site s and time t.

The Portuguese fire risk index, from which $MK_{s,t}$ derived, was selected because: i. its values originate from meteorological parameters which play an important role during the start of forest fires, ii. the used data are easily measured and available in the majority of the meteorological stations in Greece and iii. it has been used at operational and research level, and, especially, in a similar environment to Greece, providing satisfactory results [15].

The value of the $MK_{s,t}$ was used for the evaluation of $MK_{s,t}$ classes (Table 1). The class «Very high» represents sites characterized by extremely increased possibilities of fire onset, that is, maximum forest risk.

Table 1. Meteorological forest fire risk index ($MK_{s,t}$) classes in relation to $MK_{s,t}$ values [15]

$MK_{s,t}$ **value**	$MK_{s,t}$ **class**
$600 \leq MK_{s,t}$	Very high
$450 \leq MK_{s,t} < 600$	High
$300 \leq MK_{s,t} < 450$	Medium
$150 \leq MK_{s,t} < 300$	Low
$MK_{s,t} < 150$	Very low

Estimation of the most dangerous period of the year and the most dangerous period of the day. The next step was to determine, firstly, the warmest year of the period 2006-2010 for Mandrini, based on the average yearly temperature for each studied year. It was found that the year 2007 was the warmest. For this year we determined the most dangerous months for the onset of forest fires. Specifically we took into account the absolute maximum T of each month and the respective RH and estimated the values of $MK_{s,t}$ and their respective classes. The months where the $MK_{s,t}$ class was estimated as «Very high» were considered as the most dangerous and these months were found to be July and August. Note that this type of estimation process is necessary for every place because the most dangerous months, according to the aforementioned analysis, may change, depending on latitude, longitude, altitude and other factors of less importance.

After the aforementioned finding, we proceeded with the determination of the most dangerous period of the day. Specifically, we found the warmest day of the most dangerous period of the year 2007 which was the date July 25. For this day, we took into account T and respective RH on an hourly basis which were inserted in Eq.(1) in order to find the hourly $MK_{s,t}$ values for Mandrini. It was found that the meteorological risk for the onset of forest fires was maximum between 11:00 h and 16:00 h («Very high» class). Thus, the most dangerous period of the day was 11:00-16:00 h.

Estimation of $MK_{s,t}$ **at Mandrini by using T and RH data of Votanikos.** After estimating the aforementioned most dangerous periods for the warmest year of the study, 2007, the next step of our research methodology was to estimate the T values at Mandrini with the use of the remote T data from S2 site for the same periods. Similarly, RH at Mandrini was estimated by RH at Votanikos. Also, similar estimations were made for the coldest year of our study, which was found to be 2006. In this way, a more complete view of the examined time period was obtained. The estimated T and RH values were used for the estimation of the values of $MK_{s,t}$ at Mandrini.

Statistical analysis. Regarding the aforementioned estimations, at first, we conducted a well testing method, the simple linear correlation (Pearson's) analysis [22] to distinguish possible relationships between T at Mandrini and T at Votanikos. The same analysis was performed for RH. Significant correlations were confirmed for both T and RH ($P \leq 0.01$) and thus, simple linear regression analyses [23] were carrying out in order to detect the possible response functions of T and RH at Mandrini to T and RH at Votanikos, respectively, separately for 2006 and 2007.

Simple linear regression analysis is defined by Eq.(2):

$$y = a + b \cdot x \,, \tag{2}$$

where y: dependent variable, a: Y-axis intercept, b: slope and x: independent variable.

Note that linear regression models [24] and, in general, linear statistical models are commonly used in data analysis and as a part of the learning process [25].

Afterwards, as already mentioned, $MK_{s,t}$ values at Mandrini were estimated by the estimated T and RH values. In case of the confirmation of the same $MK_{s,t}$ class for both real and estimated T and RH values at Mandrini, regression lines were compared with each other [26, 27], separately for T and RH. If a positive outcome was apparent, next, the estimated T and RH values were used for the estimation of $MK_{s,t}$ values at Mandrini. The statistics was performed using IBM SPSS Statistics 21 and MS Excel 2003 with results to be considered significant at $P \leq 0.05$.

Results and Discussion

The $MK_{s,t}$ values at Mandrini, derived from T and RH of the same location, for 2006 and 2007, are shown in Table 2. Meteorological forest fire risk index was always greater in 2007 than 2006, individually for each hour, due mainly to the elevated thermal conditions in combination with lower RH in 2007. The examined index appeared its lowest values at 11:00 h with a progressive increase afterwards in the overwhelming majority of the cases, irrespective of year. The maximum values of the index were noticed at 15:00 h and 16:00 h in 2006 and 2007, respectively. From the estimated $MK_{s,t}$ values, it was demonstrated that these values were always classified as «Medium» in 2006 and «High» in 2007.

Table 2. Meteorological forest fire risk index ($MK_{s,t}$) at Mandrini based on actual air temperature (T) and relative humidity (RH) data for the years 2006 and 2007

$MK_{s,t}$						
Most dangerous period of the day [h]						
Year	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**
2006	348.6	381.6	388.2	394.9	399.0	393.2
2007	471.4	514.0	522.7	532.1	545.0	563.1

For each hour of the most dangerous period of the day, $MK_{s,t}$ values were derived from average T and RH, taking into account all the days of the most dangerous period of the year (July-August).

It is interesting to note that during the summer period of 2007, three heat waves were detected in Greece [28]. This fact, in combination with the fact that several stations in Greece reported record-breaking temperatures (up to 47 °C), making the summer of 2007 the hottest one on record [29], may justify satisfactorily the upper class of $MK_{s,t}$ at 2007 in relation to 2006.

The results of the linear regression of T and RH at Mandrini with T and RH at Votanikos, respectively, are shown in Table 3. The coefficient of determination (R^2) for T was greater than RH. In addition, the regression parameters (Y-axis intercept and slope) presented significance at $P \leq 0.01$ in all cases.

Table 3. Linear regression parameters for air temperature (T) and relative humidity (RH) at Mandrini (y) in relation to T and RH at Votanikos (x), respectively, for the years 2006 and 2007 (y = a + b·x)

a	SE(a)	b	SE(b)	R^2
2006				
T				
-5.567***	1.131	0.996***	0.035	0.690
RH				
10.277***	1.343	0.899***	0.038	0.599
2007				
T				
-4.433**	1.419	1.024***	0.042	0.616
RH				
8.573***	1.229	0.824***	0.038	0.555

a: Y-axis intercept. SE(a): Standard error of a. b: Slope. SE(b): Standard error of b. R^2: Coefficient of determination. ***, **: Significance at $P \leq 0.001$ and $P \leq 0.01$, respectively.

The estimated $MK_{s,t}$ values at Mandrini by using the estimated T and RH values, derived from the application of linear regression analysis, appear in Table 4. The change pattern of these $MK_{s,t}$ values, from 11:00 h to 16:00 h was similar, in general, to the respective one of Table 2, regardless of year.

Table 4. Meteorological forest fire risk index ($MK_{s,t}$) at Mandrini based on regressed air temperature (T) and relative humidity (RH) data for the years 2006 and 2007

$MK_{s,t}$						
Most dangerous period of the day [h]						
Year	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**
2006	339.0	370.1	390.8	405.9	407.2	393.3
2007	482.7	513.5	534.3	544.6	545.6	540.5

For each hour of the most dangerous period of the day, $MK_{s,t}$ values were derived from average regressed T and RH, taking into account all the days of the most dangerous period of the year (July-August).

It is interesting to note that these index values coincided in their classification («Medium» in 2006 and «High» in 2007) to the respective ones resulted from local T and RH data (Table 2), that is, there was absolute success (100%). Therefore, simple linear regression was proved to be a completely efficient tool for the prediction of T and RH values from which $MK_{s,t}$ values were estimated.

The comparison of the regression lines, separately for T and RH, between 2006 and 2007 showed that the aforementioned slopes (Table 3) were not significantly different from each other (t-test value: -0.51 for T and -2.30 for RH at P=0.01) and so, we proceeded with the estimation of the common slopes which had the values 1.007 for T and 0.863 for RH. Similarly, the comparison of the Y-axis intercepts (Table 3) showed that they did not differ from each other (t-test value: 0.33 for T and -2.01 for RH at P=0.01) and the common Y-axis intercepts were -4.885 and 9.417 for T and RH, respectively.

After the construction of common regression lines, individually for T and RH, we applied them to estimate the T and RH variables, from which average $MK_{s,t}$ values at Mandrini were estimated, for each hour of the most dangerous period of the day for the whole examined period. The results for 2006 and 2007 are shown in Table 5 where no substantial differences in change patterns of the $MK_{s,t}$ were detected.

Table 5. Meteorological forest fire risk index ($MK_{s,t}$) at Mandrini based on regressed air temperature (T) and relative humidity (RH) data for the years 2006 and 2007 using common regression lines

$MK_{s,t}$						
Most dangerous period of the day [h]						
Year	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**
2006	376.0	409.0	431.1	447.2	448.6	433.8
2007	437.8	466.5	486.1	495.8	497.7	462.1

For each hour of the most dangerous period of the day, $MK_{s,t}$ values were derived from average regressed T and RH, taking into account all the days of the most dangerous period of the year (July-August). There was a common regression line regarding each variable (T and RH) for both years.

Apart from the value 437.8 of $MK_{s,t}$ at 11:00 h (Table 5) which was classified as «Medium» in contrast to the respective values in Tables 2 and 4 which belonged to the «High» class, all the other estimated $MK_{s,t}$ values, totally twenty nine out of thirty [six hours (11:00 h-16:00 h) multiplied by five years (2006-2010)], coincided, regarding their classification, with those estimated from actual T and RH data. That is, a success of 97% was confirmed which was considered very satisfactory.

To our knowledge, this is the first time such a study takes place, taking into account the existing literature. Our study provides an innovative approach for the estimation of the meteorological risk, as quantified by the $MK_{s,t}$ values, concerning the onset of forest fires in the MR of Nafpaktia during the most dangerous periods of both year and day. Although this kind of study is a first promising step towards the direction of a precise estimation of the meteorological risk for the onset of forest fires, a greater number of years is required as well as other MRs to test the effectiveness of the presented research methodology. Also, a next step may include the test of this methodology to other time periods than the examined.

Conclusions

To sum up, from the analysis of the study results, after the application of a rigorous research methodology, it was possible to make a very satisfactory estimation (97% success) of the class of the average $MK_{s,t}$ at a MR of Greece, based on regressed T and RH data, for both the most dangerous period of year (July-August) and day (11:00 h-16:00 h), for five consecutive years (2006-2010). The aforementioned data were derived from remote T and RH data of an urban region, 175 Km far away, by using common regression lines (simple linear regression), resulting from regression lines created for the warmest and the coldest year of the examined year period. Our study offers new perspectives for a reliable estimation of the meteorological danger for the onset of forest fires using remote T and RH data with the aid of simple statistical models.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

[1] C. Tsiouvaras et al., Forests and grazing forest ecosystems of burned regions: Suggestions for raising and restoration, in Fires 2007, From devastation to development, Athens, Greece, 2008, pp. 169-190.

[2] C. Kosmas et al., Erosion of soils after fires, measures of handling, in Fires 2007, From devastation to development, Athens, Greece, 2008, pp. 125-149.

[3] A. Chronopoulou-Sereli et al., Evaluation of the meteorological danger for the prevention of fires, in Fires 2007, From devastation to development, Athens, Greece, 2008, pp. 191-213.

[4] A. Holsten et al., Evaluation of the performance of meteorological forest fire indices for German federal states, Forest Ecology and Management. 287 (2013) 123-131.

[5] A. Chronopoulou-Sereli et al., General and Specific Topics of Bioclimatology, Applications-Exercises, Ziti Publ., Thessaloniki, Greece, 2012.

[6] C. Chandler et al., Fire in Forestry. Volume 1. Forest fire behavior and effects, John Wiley & Sons Inc., New York, 1983.

[7] A. Arpaci et al., A collection of possible fire weather indices (FWI) for alpine landscapes, ALP FFIRS project report, 2010.

[8] B. Sol, Estimation du risque météorologique d’incendies de forêts dans le Sud-est de la France, Revue Forestière Française. XLII (1990) 263-271.

[9] J.-C. Drouet, B. Sol, Mise au point d’un indice numérique de risque météorologique d’incendies de forêts, Forêt Méditerranéenne. 14(2) (1993) 155-162.

[10] A.G. McArthur, Weather and grassland fire behaviour, Department of National Development, Forestry and Timber Bureau Leaflet No. 100, Canberra, Australia, 1966.

[11] A.G. McArthur, Forest fire danger meter, Mk 5, Forest Research Institute, Forestry and Timber Bureau, Canberra, Australia, 1973.

[12] A.G. McArthur, Grassland fire danger meter, Mk 5, Country Fire Authority of Victoria, Melbourne, Australia, 1977.

[13] I.R. Noble, G.A.V. Bary, A.M. Gill, McArthur's fire-danger meters expressed as equations, Australian Journal of Ecology. 5 (1980) 201-203.

[14] C.E. Van Wagner, Development and structure of the Canadian forest fire weather index system, Technical Report 35, Canadian Forestry Service, Canada, 1987.

[15] V. Gouma, A methodology for the spatial-temporal assessment of forest fire meteorogical risk in mountainous areas: application in mountain Parnes, Ph.D. dissertation, Dept. Gen. Sci., Agric. Univ., Athens, Greece, 2001.

[16] M. Zorro Gonçalves, L. Lourenço, Meteorological index of forest fire risk in the Portuguese mainland territory, in: International Conference on Forest Fire Research, Coimbra, Portugal, 1990, pp. 1-14.

[17] I. Aguado et al., Estimation of meteorological fire danger indices from multitemporal series of NOAA-AVHRR data, in 3rd International Conference on Forest Fires Research, 14th Conference on Fire and Forest Meteorology, Coimbra, Portugal, 1998, pp. 1131-1147.

[18] Y. Liu et al., Analysis of the impact of the forest fires in August 2007 on air quality of Athens using multi-sensor aerosol remote sensing data, meteorology and surface observations, Atmospheric Environment. 43(21) (2009) 3310-3318.

[19] J. Chalatsis, Mountainous Nafpaktia, 2017. Available: http://www.nafpaktos.gr.

[20] Anonymous, Google Earth, 2017. Available: https://www.google.com/earth/.

[21] K. Chronopoulos et al., An artificial neural network model application for the estimation of thermal comfort conditions in mountainous regions, Greece, Atmósfera. 25(2) (2012) 171-181.

[22] P. Roussos et al., Relations of environmental factors with the phenol content and oxidative enzyme activities of olive explants, Scientia Horticulturae. 113(1) (2007) 100-102.

[23] A. Matsoukis, K. Chronopoulos, Estimating inside air temperature of a glasshouse using statistical models, Current World Environment. 12(1) (2017) 1-5.

[24] G. Feng et al., Two paradoxes in linear regression analysis, Shanghai Archives of Psychiatry. 28(6) (2016) 355-360.

[25] A.C. Rencher, G.B. Schaalje, Linear Models in Statistics, 2nd ed., John Wiley & Sons Inc., Hoboken, New Jersey, 2008.

[26] P.I. Kaltsikes, Simple Experimental Designs, Stamoulis Publ., Athens, Greece, 1997.

[27] J.H. Zar, Biostatistical Analysis, 4th ed., Prentice Hall, Upper Saddle River, New Jersey, 1999.

[28] A. Kamoutsis et al., A comparative study of human thermal comfort conditions in two mountainous regions in Greece during summer, Global Nest Journal. 12(4) (2010) 401-408.

[29] Ø. Hodnebrog et al., Impact of forest fires, biogenic emissions and high temperatures on the elevated Eastern Mediterranean ozone levels during the hot summer of 2007, Atmospheric Chemistry and Physics. 12(18) (2012) 8727-8750.