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J. Environ. Biol.
33, 817-821 (2012)
ISSN: 0254-8704
CODEN: JEBIDP

Determination of incoming solar radiation in major tree species in Turkey

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Publication Data

Paper received:
11 March 2011

Revised received:
20 August 2011

Accepted:
16 October 2011

Abstract

Light requirements and spatial distribution of major forest tree species in Turkey hasn't been analyzed yet. Continuous surface solar radiation data, especially at mountainous-forested areas, are needed to put forward this relationship between forest tree species and solar radiation. To achieve this, GIS-based modeling of solar radiation is one of the methods used in rangelands to estimate continuous surface solar radiation. Therefore, mean monthly and annual total global solar radiation maps of whole Turkey were computed spatially using GRASS GIS software "r.sun" model under clear-sky (cloudless) conditions. 147498 pure forest stand point-based data were used in the study for calculating mean global solar radiation values of all the major forest tree species of Turkey. Beech had the lowest annual mean total global solar radiation value of 1654.87 kWh m^{-2}, whereas juniper had the highest value of 1928.89 kWh m^{-2}. The rank order of tree species according to the mean monthly and annual total global solar radiation values, using a confidence level of $p < 0.05$, was as follows: Beech < Spruce < Fir species < Oak species < Scotch pine < Red pine < Cedar < Juniper.The monthly and annual solar radiation values of sites and light requirements of forest trees ranked similarly.

Key words

Solar radiation modeling, GIS, Forest tree species

Introduction

Solar radiation is the basis of life on earth (Kimmins, 1997) and access to sunlight is crucial for plants. Less than 1% of the solar energy reaching earth is transformed into organic matter, 30% is reflected back to outer space, and the remainder generates the heat upon which all living organisms depend (Odum and Barrett, 2005). The absence of sunlight or insufficient sunlight not only impairs the plants' growth but also changes their entire physiology and morphology (Uemura *et al.*, 2000). Solar radiation plays an important role in determining the patterns of regional plant formations (Irmak, 1970; Pierce *et al.*, 2005; Walton *et al.,* 2005). Particular species can manifest different growth responses under varying conditions of solar radiation; these responses may vary more drastically when considered across many species (Bueno-Bartholomei and Labaki, 2003). Solar radiation affects plant distribution by affecting the basic habitat variables. These variables include air, soil temperature, snow melting period and time, soil and air humidity, photosynthesis and evapotranspiration (Nouvellon *et al.*, 2000).

Global solar radiation data are available to be interpreted throughout 159 weather stations in Turkey since 1964 (Aksoy, 1997).While only these solar radiation data have used many studies, other studies have also put forward the relationship between the solar radiation data and the other meteorological variables such as relative humidity (Sözen and Arcakhoglu, 2005).

The artificial neural network (ANN) method has been used to produce station-based estimates and maps. For example, contoured monthly values were produced by using the data taken from 17 different stations (Sözen *et al.*, 2004 a, b). A solar potential map of Turkey was constructed by evaluating the data from 150 different stations using GIS software; the kriging spatial interpolation method was utilized (Evrendilek and Ertekin, 2007). Furthermore, another study performed by the General Directorate of Electrical Power Resources Survey and Development Administration produced a solar radiation potential atlas with 500 m resolution. This study implemented the solar radiation modeling ability of GIS.

In order for environmental managers to perform effective and definitive decision-making concerning the areas in question, spatially continuous data are needed. Similarly, in order for scientists to make accurate interpretations, precise spatially continuous data are needed(Li and Heap, 2008). These data are obtained in three ways: 1) various interpolation methods using point data measured weatherstations, 2) directly from meteorological satellite, 3) modeling studies developed for one or more specific natural phenomena. In the first method, meteorological station data on solar radiation are point based and required interpolation for converting continuous data. In the second method, meteorological satellite does not provide high geometric resolution continuous data. Therefore, GIS and modeling techniques have become increasingly effective tools in natural resource management and biological conservation.

Improvements in geographical information technologies, the increasing accessibility of digital data and the fact that GIS is progressively becoming an easier and more user-friendly technology are all contributing to these areas of research through their positive effects on studies in the natural sciences (Mitasova and Neteler, 2004).In this study, annual and monthly total global solar radiation spatial continuous data values for Turkey under clear-sky conditions were determined by a solar radiation model embedded in a GIS. Mean total global solar radiation values of Turkey's major forest tree species were calculated and compared to each other statistically.

Materials and Methods

Modeling of solar radiation:Elevation, slope and aspect variables of solar radiation model were determined using SRTM3 data. SRTM3 data are provided at 90m resolution (JPL 2005). The DEM accuracy requirements were ±16 m absolute and ±10 m relative vertical accuracy. The relative horizontal accuracy was 20 m (Duren 1998; Bamler 1999).

The stand maps supplied by the Mapping and Photogrammetric Division of the General Directorate of Forestry were processed as follows. The polygon-based vector data (stand types map) in the GIS database was transformed to point-based data by using the "feature to point" command of the GIS software. Each sub-stand was represented by a point (Fig. 1).

Calculations of the solar radiation values were made using open-source GIS software by means of GRASS's "r.sun" modeling command (GRASS Development Team, 2008). This command has been globally and regionally formulated to satisfy the needs of various scientific disciplines (hydrology, climatology, ecology, natural sciences, solar cells and engineering) (Neteler and Mitasova, 2002). The model estimates the raster maps of direct, diffused and ground-reflected irradiation for a given day, position, surface and atmospheric condition. This model can also compute real-sky radiation if required values and maps are entered into the system (Hofierka and Suri, 2002).

Annual and monthly total global solar radiation values for Turkey were computed with "r.sun" model. Maps such as longitude-latitude, elevation, slope and aspect were taken into account in the calculations along with default values and parameters such as albedo and linke atmospheric turbidity. Subsequently, mean total global solar radiation values of pure stand(s) of each tree species red pine (*Pinus brutia* Ten), black pine (*Pinus nigra* Arnold.), Scotch pine (*Pinuss ylvestris* L.), juniper (*Juniperus excelsa*Bieb.), cedar (*Cedrus libani* A. Rich.), spruce (*Picea orientalis* (L.) Link.), fir (*Abies* spp.) species, beech (*Fagus orientalis*Lipsky) and oak (*Quercus* spp.)were calculated. The number of sample points for each tree species was as follows: 6131 in beech, 505 in spruce, 2276 in fir, 5727 in oak, 53486 in black pine, 13666 in Scotch pine, 62119 in red pine, 2392 in cedar and 1196 in juniper.

Statistical Analyses: Average, average standard error, median, mode, standard deviation, variance, range, and minimum and maximum values of the total global solar radiation for the areas of pure stands of forest-forming species were calculated (Orhunbilge, 2002; Kalipsiz, 1981). Since the ongoing debate over the causes leading to non-pure stands has still not been resolved, and because of complex interactions within the mixed stands, non-pure and mixed stands were excluded from the calculations. The probability distributions of the data analyzed for the communities were not normal, and nonparametric methods were therefore used to compare the solar radiation values by tree species. The Kruskal-Wallis test was performed to detect one or more species having values different from the others. The process was taken one step further by performing the Mann-Whitney U test to detect the differences (Kalipsiz, 1981; Özdamar, 2002; Senol, 2004).

Results and Discussion

The main forest-forming tree species of Turkey are red, black and Scotch pine, juniper, cedar, spruce, fir, beech and oak subspecies (Odabasi ve Ark., 2004).When all the forest tree species were considered, beech had the lowest annual mean total global solar radiation value of 1654.87 kWh m^{-2}. Juniper had the highest value of 1928.89 kWh m^{-2}. The rank order of tree species according to the mean annual total global solar radiation values was as follows: juniper > cedar > red pine > Scotch pine > black pine > oak species > fir species > spruce >beech (Table 1, 2). As this arrangement indicates, light-demanding trees occupy the areas where solar

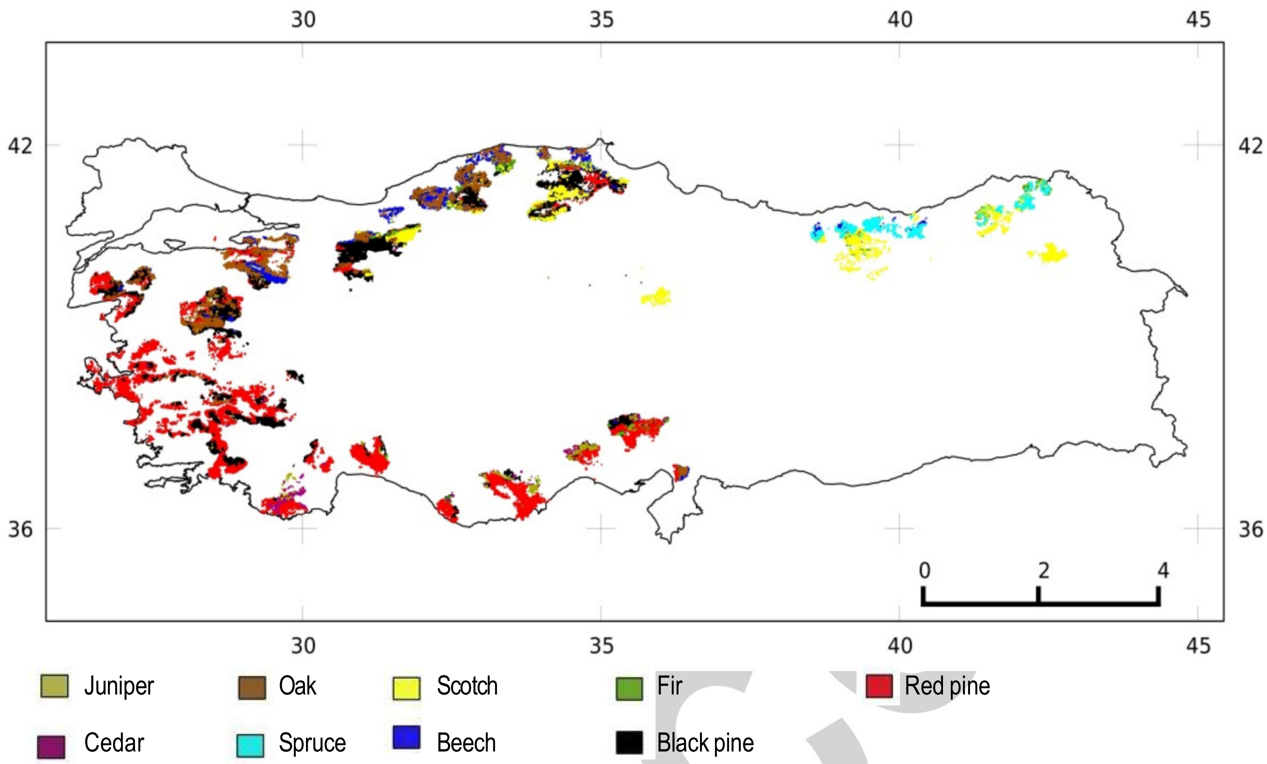

Fig 1 : The distribution of the utilized data over map of Turkey.

Table 1: Summary statistics of species' annual total global solar radiation values (k Wh m^{-2}).

	Beech	Spruce	Fir	Oak	Black pine	Scotch pine	Red pine	Cedar	Juniper
Average	1654.87	1671.79	1683.96	1739.75	1782.52	1794.85	1817.49	1870.27	1928.89
Standard error	3.50	13.44	5.82	3.17	1.00	2.20	0.87	5.93	6.82
Median	1647.52	1683.05	1679.29	1755.20	1803.28	1824.69	1855.23	1919.28	1973.4
Mode	1214.39	1167.56	1745.34	1210.28	1543.96	1896.13	1992.7	1929.02	2130.58
Standard deviation	274.38	302.02	277.46	239.60	232.42	257.74	217.91	289.85	235.88
Variance	75284457	91213730	76984146	57407258	54019387	66427977	47485593	84011403	55639589
Range	1344.62	1260.98	1275.59	1273.44	1340.00	1370.07	1468.49	1414.70	1232.79
Lowest	974.17	1021.79	1039.59	1026.89	999.09	968.66	825.48	932.36	1123.26
Highest	2318.80	2282.77	2315.19	2300.33	2339.09	2338.73	2293.97	2347.07	2356.05

Table 2 : Mean monthly solar radiation amounts for forest-forming tree species (using a p<0.05 confidence level and grouped according to the Mann-Whitney U test).

Month	Beech	Spruce	Fir	Oak	Black pine	Scotch pine	Red pine	Cedar	Juniper
January	54.69^{a}	55.95^{ba}	56.21^{abc}	64.79^{d}	66.95^{e}	66.31^{f}	74.28^{g}	79.44^{h}	86.03^{k}
February	85.36^{a}	87.04^{ab}	87.14^{ab}	95.70^{c}	98.46^{d}	98.43^{e}	105.18^{f}	110.51^{g}	117.20^{h}
March	125.96^{a}	127.61^{ba}	128.18^{cb}	134.78^{d}	138.18^{e}	138.92^{f}	142.65^{g}	147.56^{h}	153.27^{k}
April	175.86^{a}	177.31^{ba}	178.65^{cb}	182.07^{d}	186.24^{e}	187.95^{f}	187.53^{g}	191.66^{h}	196.08^{k}
May	208.82^{a}	210.10^{b}	212.07^{c}	211.70^{db}	216.38^{e}	218.94^{f}	214.32^{g}	217.54^{h}	220.13^{kf}
June	222.68^{a}	223.80^{b}	226.13^{c}	223.84^{d}	228.70^{e}	231.62^{f}	225.00^{gb}	227.75^{e}	229.40^{h}
July	216.33^{a}	217.49^{b}	219.69^{c}	218.15^{db}	222.92^{e}	225.69^{f}	219.87^{gb}	222.81^{h}	224.78^{k}
August	190.88^{a}	192.28^{b}	193.87^{cb}	195.40^{d}	199.80^{e}	201.90^{f}	199.42^{g}	203.00^{h}	206.55^{k}
September	150.86^{a}	152.45^{ba}	153.35^{cb}	158.66^{d}	162.44^{e}	163.67^{f}	165.52^{g}	170.18^{h}	175.33^{k}
October	101.27a	102.82ba	103.20cb	110.81d	113.78e	114.07^{e}	119.42^{f}	124.44^{g}	130.57^{h}
November	67.02a	68.61ba	68.63^{cb}	77.24^{d}	7964^{e}	79.30^{e}	86.76^{f}	92.02^{g}	98.71^{h}
December	55.14a	56.34ba	56.83^{ca}	66.62^{d}	69.01^{e}	68.04^{f}	77.55^{g}	83.36^{h}	90.83^{k}
Total	1654.87^{a}	**1671.79^{ba}**	**1683.96^{cb}**	**1739.75^{d}**	**1782.52^{e}**	**1794.85^{f}**	**1817.49^{g}**	**1870.27^{h}**	**1928.89^{k}**

radiation is more abundant, whereas canopy-tolerant trees seem to prefer the areas where solar radiation is relatively less plentiful. Mean total global solar radiation values for beech, spruce and fir, all canopy-tolerant trees known to tolerate lower amounts of solar radiation, were low compared with values for red and Scotch pine, two species that generally occupy areas where sunlight is plentiful. Cedar and juniper, on the other hand, can grow under insufficient light conditions and had the highest solar radiation values. Black pine, the other pine species known to tolerate insufficient light, occupied the middle of the range of values.

It was noteworthy that less light-demanding species, e.g., cedar and juniper, occupied higher ranks according to solar radiation values. Such species occupy high elevations in the southern part of the country (Kavgaci, 2007). The higher solar radiation values obtained in the habitats where these species are found are therefore perfectly normal. Indeed, since the number of cloudy and foggy days in the mountainous regions will be higher than the number obtained for regions having clear-sky conditions, the actual solar radiation values of cedar and juniper are in fact expected to be lower than that of red pine.

From the standard deviation of the total global annual solar radiation belonging to the areas that these species occupied, it was determined that the number of trees preferring the shadowy sites was more than the number in the sites occupied by the light-demanding species (Table 1). Variance values exhibited a similar tendency. The species preferring the shadowy sites choose these areas because they can tolerate insufficient light conditions (owing to dense canopy closure). Thus, species that can tolerate shadow were expected to range over an interval of solar radiation values broader than the range of radiation values for species that cannot tolerate such conditions. The data in Table 1 contradict this assumption. The lowest value represented one single number. However, standard deviation and variance values were more meaningful because they were based on all available data.

Fir species that occur as forest trees in Turkey are Abies cilicica, *A. nordmanniana* subsp *nordmanniana, A. nordmanniana* subsp *bornmülleriana and A.nordmanniana* subsp *equi-trojani* (Akkemik and Oral, 2011). Such species behaved as typical shade-tolerant trees. However, their mean monthly and annual total global solar radiation values ranked higher than those of spruce and beech. The number of oak species found in Turkey is 18 (Yaltirik, 1988b). Solar radiation values of oak species were lower than those of the fir species (Figure 2, Table 2). That some particular oak species were shade-tolerant might well explain this result, because shade-tolerance thresholds of some oak species differ from one another. For example, the evergreen oak species *Quercus sessiliflora* and *Q. pedunculata*are tolerant of semi-light conditions (Çepel, 1988).

Although Scotch pine is a light-demanding species, its range generally coincides with the northern part of the country. For this reason, its calculated total global solar radiation was lower than those of juniper and cedar. Scotch pine generally prefers the southern aspects of the regions in which it is found today (Mayer and Aksoy, 1998). Thus, Scotch pine in northern Turkey compensates for its adverse situation by growing in southern aspects of those regions, so that its solar radiation budget is somewhat balanced.

For all species, June had the highest solar radiation value of any month (Table 2). All shade-tolerant species had similar monthly solar radiation values. Species preferring sunny sites constituted another group (Table 2).Red pine, the typical tree species of the Mediterranean climate, is generally found in lower-elevation zones (Mayer and Aksoy, 1998).Nevertheless, based on the solar radiation values for June and July, red pine was placed in the same group as spruce. During this period, water shortages reach a peak, and red pine is found where the solar radiation is rather low. The ranges of the species according to the monthly solar radiation values were similar to the ranges according to total global solar radiation. The results, achieved by the method which was driven to reach global solar radiation values, and the common light requirements of trees showed harmony. Besides, re-execution of the model within the addition of some complementary parameters such as relative humidity, temperature, reflected radiation, cloudiness etc. assumed to provide more efficient results.

Shade-tolerant species were found where the solar radiation was lower, and shade-intolerant tree species were found where the solar radiation was higher. If additional variables such as humidity, wind intensity and direction, and particles suspended in the air had been used in the calculation of solar radiation values, the rank order of tree species based on the total global annual solar radiation values could possibly have been made using parametric methods. If such variables had been included in this real-sky (overcast) solar radiation calculation modeling, more comprehensive results could have been possible. The monthly and annual solar radiation values of sites and light requirements of trees ranked similarly.

Acknowledgments

The authors are grateful to the General Directorate of Forestry for forest tree data. This study was funded by the Istanbul University Scientific Research Projects Executive Secretary, project number 493.

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