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APPLICATION OF TIME-SERIES METHODS FOR THE MODELING OF SUNSHINE DURATION SEQUENCES

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Abstract. *This paper presents the application of statistical methods to determine the length of solar radiation based on the data obtained from the meteorological station Negotin, and we may presume that these data are also representative for a wider area of northeastern Serbia. Negotin is a town in northeastern Serbia, in the Bor District, with the population of ca. 17000, near the border with Romania and Bulgaria. The results of the application of statistical methods allow us to predict the future trend of the time series, i.e. to predict the sunshine duration in the sample area.*
We performed the measurements using several models to predict the trend of the time series of sunshine duration, whereby it was essential to use the most suitable model. Selection and evaluation of models were applied to a series of annual sums of sunshine duration observed between 1991 and 2011 in the meteorological station in Negotin. Using an ARIMA model and the trends method, we obtained the predictions of sunshine duration in Negotin up to 2015. The prediction results show the reduced sunshine duration on annual basis over the observed time of prediction.

Key words: *meteorological time series, ARIMA model, trends method, sunshine duration*

1. INTRODUCTION

Generally, energy is one of the three basic elements of survival of the human species on Earth, together with materials and food. The largest source of energy on Earth is the Sun, which is simultaneously circulating and being deposited. Solar energy is clean and inexhaustible, and its use has the best prospects for the future. The reduction of conventional energy resources and increase of energy demand in the modern world only confirm this view.

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It is known that solar energy is very unevenly distributed, with significant spatial and temporal (seasonal and non-periodical) fluctuations [1-6]. Solar radiation energy that reaches the Earth's surface and a specific location depends primarily on the duration of the radiation. WMO defines the duration of sunshine (h- hours) as the period in which the tensity of direct solar radiation that reaches the Earth's surface is greater than 120 W/m^2.

Duration of solar radiance and intensity of solar radiation in a certain location varies daily and annually [7, 8]. Insolation of a given location on Earth and the amount of heat coming from the Sun in a short period of time is directly dependent on the degree of cloudiness. In his paper, Stamenic [9] states that the most favorable areas in Serbia have a large number of sun hours and that the annual ratio of actual irradiation to the total possible irradiation is approximately 50 % [10-14].

There is an increasing number of studies and papers whose aim is to determine to what extent the climate is changing and what the predictions for the future are. The statistical approach is the most important in the analysis of time series.

Various statistical procedures can be used for the modeling of time series for sunshine duration, including various models based on the application of statistical time-series analysis. Modeling of time series assumes that a time series is a combination of a formula and a random error [9, 15, 16]. There are several models for time series prediction: autoregressive models [17], moving-average models, linear regression models [18], as well as combined models, i.e. autoregressive integrated models of moving average (ARIMA). These models have become very popular for predicting series of meteorological elements in an observed time of prediction. The models are simple to use and useful for predicting data in meteorology and hydrology. In this paper, we used an ARIMA model and the trends method to predict the trend of sunshine duration.

2. Methodology

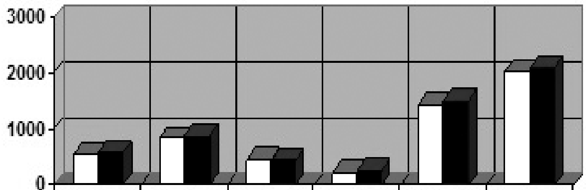
To monitor trends of annual sunshine duration in the region of Negotin, we used a sequence of data for the periods between 1961 and 1990 and between 1981 and 2010, for the main meteorological station Negotin (latitude 44°13´N, longitude 22°31´E, H = 42m elevation above mean sea level).

In order to analyze the time series of sunshine duration trends, observed in the period from 1991 to 2011 at the meteorological station Negotin, we used the trends method and an ARIMA model, version 3.1.0. The processing of the results was performed by means of software program Statistics, Release 8, developed by Stat Soft Inc., Tulsa, OK, USA.

3. Results and Discussion

The sum of annual sunshine duration for the period from 1961 to 1990 in northeastern Serbia (Negotin meteorological station) was 2 035 hours on average, which is about 46% of the possible duration (Figure 1) [12]. Solar radiation in the period from 1981 to 2010 showed considerably higher values compared to the multi-year average. Figure 1 shows the average values of the actual sunshine duration in the spring, summer, and winter, or the vegetation period.

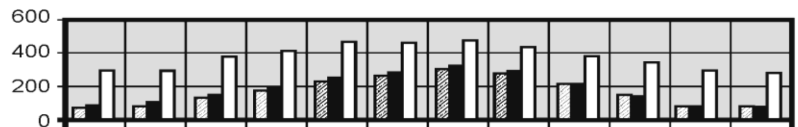
It can be observed from Figure 1, that the spring has more sunshine hours (569.9) than autumn (424.2), which coincides with the annual course of air temperature. The winter period has the fewest hours of sunshine, only 241.2, while the most hours of sunshine occur in the summer (874.0). In the vegetation period the number of sunshine hours is large (1 511.0 h), which has a positive impact on the vegetation. In the vegetation period between 1961 and 1990, the actual insolation was 1 455.0 h (55.9% of the possible 2 604.0 hours), whereas for the period between 1981 and 2010 it was 1 511.0 h (58.0% of the possible number of hours of insolation).



	spring	summer	autumn	winter	veg.peri	annual
□ 1961/1990	534.7	838.6	446	216.6	1455	2035.9
■ 1981-2010	569.9	874	424.2	241.2	1511	2109.7

Fig. 1 Average values of the actual sunshine duration for different seasons of the year and for the vegetation period expressed in hours [h]

Figure 2 presents the average monthly sunshine duration. For the period from 1981 to 2010, during the calendar year, higher values of the average monthly sunshine duration occur in the first 8 months whereas lower values occur during the final 4 months. The highest percentage of insolation occurs in the month of July amounting to ca. 310.1 h, which is about 66.3% of the possible insolation. The lowest percentage of insolation occurs in December, about 22.5% of the possible insolation, because during this month the degree of cloudiness is higher than during other months.



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1961-1990	71.4	78.1	128.8	176.3	229.6	261.9	301.2	275.5	210.5	151.8	83.7	67.1
■ 1981-2010	80.2	99	141.3	185.5	243.1	279.8	310.1	284.1	208.4	139	76.8	62
□ possible	288	294	369	405	458	462	468	432	379	342	288	276

Fig. 2 Average monthly sunshine duration expressed in hours [h]

Figure 3 shows the annual amount of solar radiation. During the observed period, the highest values of solar radiation were registered in 2011 – 2 497.8 hours. The minimum value of solar radiation recorded at the Negotin station was only 1 958.2 hours in 2005.

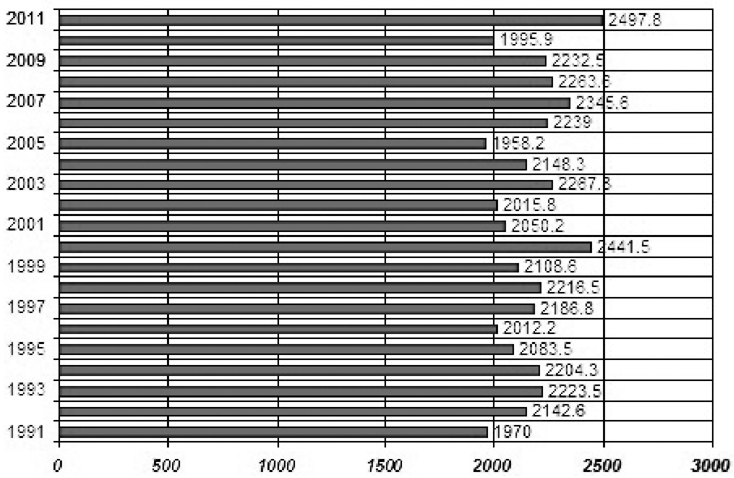
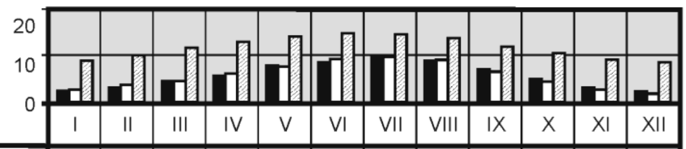


Fig. 3 Annual sums of sunshine duration in Negotin (northeastern Serbia), in hours [h]

In addition to the total annual number of sunshine hours, the number of sunshine hours during certain months is also significant. Insolation is the lowest in the winter months, and the highest when the days are long, the temperature high, and relative humidity low. Sunshine duration and cloudiness are negatively correlated – if cloudiness increases, sunshine duration decreases. The highest insolation of about 10 hours per day is in July and the lowest in December, when the sun shines averagely 2 hours per day, as shown in Figure 4.



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
S1961/90	2.3	2.8	4.2	5.9	7.4	8.7	9.7	8.9	7	4.9	2.8	2.2
S1981/10	2.6	3.5	4.6	6.2	7.8	9.3	10	9.2	6.9	4.5	2.6	2
S0	9.1	10.3	11.8	13.3	14.6	15.3	15	13.8	12.4	10.8	9.5	8.7

Fig. 4 Average daily sunshine duration in Negotin (northeastern Serbia) expressed in hours [h], S – real time, S_o – astronomical

The value of the data for average annual cloudiness, given in Figure 5 for the period from 1981 to 2011, shows that the sky in Negotin during a single year is more clouded than clear. It can be concluded that the minimum of cloudiness was registered in 2000, and the maximum in 1996 [24].

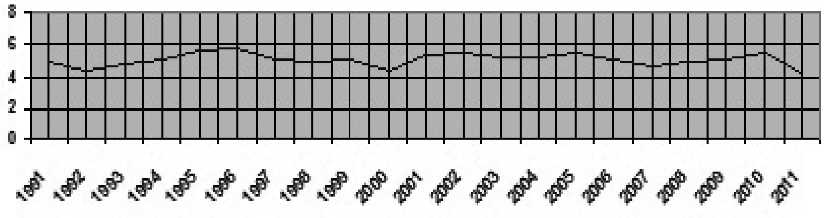


Fig. 5 Average annual cloudiness

4. THE TRENDS METHOD

Many researchers suggest that the trends method is the most complex of all statistical methods of dynamic analysis of mass phenomena. It can be said that this is the most important method for a time-series analysis. Based on this method we estimate and predict future trends and development of phenomena. Sekaric [14] states that the practice shows that the trends method is best suited for the analysis of the dynamic time series that are given in one-year durations.

Trends and development of sunshine duration on annual basis shows a straight-line direction and the value of the trend ($\hat{y}$) in a general explicit expression can be mathematically expressed as:

$$\hat{y} = a + bx \tag{1}$$

where a and b are parameters that determine the position and the incline of the trend line. Quantity x is the independent variable that observes time. The trend must satisfy the following conditions:

- the sum of the distances of original data from the trend line must be equal to zero, i.e.:

$$\sum (y_i - \hat{y}) = 0 \tag{2}$$

- the sum of the squared deviations of original data from the trend line must be less than the sum of the squared deviations of original data

$$\sum (y_i - \hat{y})^2 = \min \tag{3}$$

Using expression 3, we obtain the system of equations from which we calculate parameters a and b, which satisfy the condition of least squares:

$$\sum y_i = na + b \sum x_i \tag{4}$$

$$\sum x_i y_i = a \sum x_i + b \sum x_i^2 \tag{5}$$

By solving this system of equations with the conditional method, we obtain the value of parameters a and b, which will serve to calculate the trend for each period. The parameters a and b can be calculated using the formulas:

$$a = \frac{\sum y_i}{n} \tag{6}$$

$$b = \frac{\sum x_i y_i}{\sum x_i^2} \tag{7}$$

Analytical determination of the trend function of sunshine duration and the numerical calculation of the value of an element of that sunshine duration is shown in Table 1.

Table 1 Analytical determination of the trend function of sunshine duration and the numerical calculation of the value of an element of that sunshine duration

Year	Sunshine duration [h], y_i	x_i	x_i^2	$x_i - y_i$	y
1991	1970.0	-10	100	-19700.0	2094.3
1992	2142.6	-9	81	-19283.4	2102.0
1993	2223.5	-8	64	-17788.0	2109.8
1994	2204.3	-7	49	-15430.1	2117.5
1995	2083.5	-6	36	-12501.0	2125.2
1996	2012.2	-5	25	-10061.0	2132.9
1997	2186.8	-4	16	-8747.2	2140.7
1998	2216.5	-3	9	-6625.8	2148.4
1999	2108.6	-2	4	-4217.2	2156.1
2000	2441.5	-1	1	-2441.5	2163.9
2001	2050.2	0	0	0	2171.6
2002	2015.8	1	1	2015.8	2179.3
2003	2267.8	2	4	4535.6	2187.1
2004	2148.3	3	9	6444.9	2194.8
2005	1958.2	4	16	7832.8	2202.5
2006	2239.0	5	25	11195.0	2210.3
2007	2345.6	6	36	14073.6	2218.0
2008	2263.6	7	49	15845.2	2225.7
2009	2232.5	8	64	17860.0	2233.4
2010	1995.9	9	81	17963.1	2241.2
2011	2497.8	10	100	24978.0	2248.9
n = 21	$\sum y_i = 45604.2$	$\sum x_i = 0$	770	5948.8	

According to this method, the expected sunshine duration in 2015 will be 2 279.8 hours.

5. ARIMA MODEL

Chronologically ordered numerical sunshine duration data in northeastern Serbia (meteorological station Negotin) represent time series. It is possible to apply the time-series calculation by using the Box-Jenkins' iterative approach [9, 19, 20] and an ARIMA model.

Analysis and prediction of sunshine duration by means of ARIMA model are shown in Figure 6.

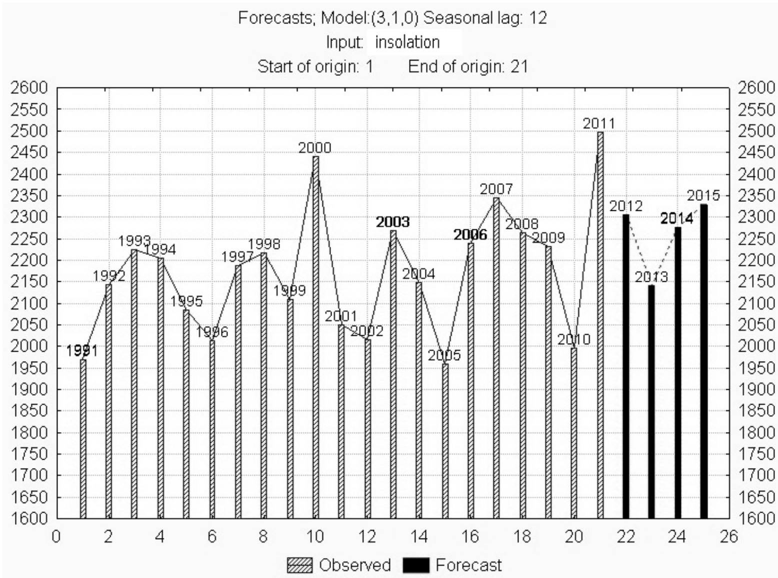


Fig. 6 Annual sunshine duration forecasts (2012-2015)

The results of the analysis and prediction of sunshine duration show a decrease of 166.7 hours per year, from the initial 2 497.8 hours to 2 331.1 hours in the last predicted year, as shown in Figure 6.

Table 2 Sunshine duration forecasts for the period from 2012 to 2015 using an ARIMA model

	Forecasts; Model:(3,1,0) Seasonal lag: 12 (1.sta) Input: osuncavanje Start of origin: 1 End of origin: 21		
CaseNo.	Forecast	Lower 90.0000%	**Upper 90.0000%**
2012	2304.258	1999.653	2655.263
2013	2139.969	1846.847	2479.614
2014	2277.148	1963.749	2640.562
2015	2331.079	1975.635	2750.472

6. Conclusion

Results and analyses of sunshine duration predictions in the observed time indicate a decrease in the number of sunshine hours, obtained by applying the trends method and an ARIMA model.

According to the trends method, the expected sunshine duration is 2 279.8 hours and the ARIMA method prediction is 2 331.1 hours. The difference in prediction between these two methods is 51.3 hours. This is a practical indicator of the sensitivity of different models and evidence that they should be applied carefully.

The multi-year sequence of sunshine duration for the period from 1991 to 2011 is an increasing one, with a very favorable seasonal schedule. Resources of solar radiation in Serbia are above the European average, so it is possible to use this type of energy effectively and in a long term. This is evidence that any investment in the field of solar energy in this region is justified and cost-effective. The broader social significance of the use of solar energy is reflected in the substitution of fossil fuels, environmental protection, the prospects of using solar energy in many branches of industry, economic and business development, and increased standard of living and quality of life.

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PRIMENA METODA VREMENSKIH SERIJA ZA MODELIRANJE NIZOVA DUŽINE TRAJANJA SIJANJA SUNCA

Rad predstavlja rezultate primene statističkih metoda u određivanju dužine trajanja sijanja Sunca na osnovu podataka dobijenih sa meteorološke stanice Negotin, pri čemu se može smatrati da ovi podaci imaju karakter reprezentativnosti i za šire područje severoistočne Srbije. Rezultati primene statističkih metoda daju mogućnost predviđanja trenda budućih vremenskih serija, odnosno mogućnost predviđanja dužine trajanja sijanja Sunca na uzorkovanom prostoru. U radu je korišćeno nekoliko modela u predviđanju trenda vremenskih serija dužine trajanja sijanja Sunca, pri čemu je najvažnije primeniti odgovarajući model. Izbor i ocena modela primenjeni su na seriju godišnjih suma dužine trajanja sijanja Sunca posmatranih u periodu 1991÷2011. god. na meteorološkoj stanici u Negotinu. Primenom ARIMA metoda i metode trenda u radu su data predviđanja trajanja sijanja Sunca na području Negotina (severoistočna Srbija) do 2015. godine. Rezultati predviđanja pokazuju smanjenje dužine trajanja sijanja Sunca na godišnjem nivou u posmatranom vremenu predviđanja.

Ključne reči: *meteorološka vremenska serija; ARIMA model; metod trenda, dužina trajanja sijanja Sunca*