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# Analysis of insolation potential of Knjaževac Municipality (Serbia) using multi-criteria approach

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ABSTRACT

The subject of this paper is to identify the most suitable location for the installation of solar panel power plant in the Municipality of Knjaževac (East Serbia). Digital elevation model (DEM) of the area of interest was constructed using Geomedia Pro Grid module. The potential insolation of municipality was determined using the obtained DEM for the summer and winter solstice which represents longest and shortest day in a year (June 21st and December 21st, 2015), which allowed calculating the mean annual potential insolation. Six classes of land use were identified using multispectral analysis of Landsat 8 satellite images. Three best locations for the solar panel installation were identified by multi-criteria AHP analysis using mean potential insolation, mean cloudiness for corresponding months, mean temperature, grade and aspect, land use classes and simplicity of availability of the locations. The obtained data indicate that the use of solar radiation in Knjaževac municipality is economically feasible as a supplementary source of energy.



**Contents**



## 1. Introduction

In conditions of the global energy crisis, the provision of alternative sources of energy is set as a priority goal, both at the local and global level. Emphasized necessity for improvement of energy balance, together with the natural resource protection, gives great significance to renewable energy resources (hydro-energy, solar, wind, geothermal, energy of tide and low tide, sea waves, biomass, etc.).

Energy production from solar radiation is in a constant expansion in the world, but its share in the total world energy production is still a symbolic one (0.54% in 2013). At the beginning of the 21st century, some states have passed from the stage of the experiment to the massive use of solar energy for the needs of the population and economy. According to data for 2014, the largest installed capacity of photovoltaic (PV) power plants have Germany (21.2% of world capacity), China (15.6%), Japan (12.9%), Italy

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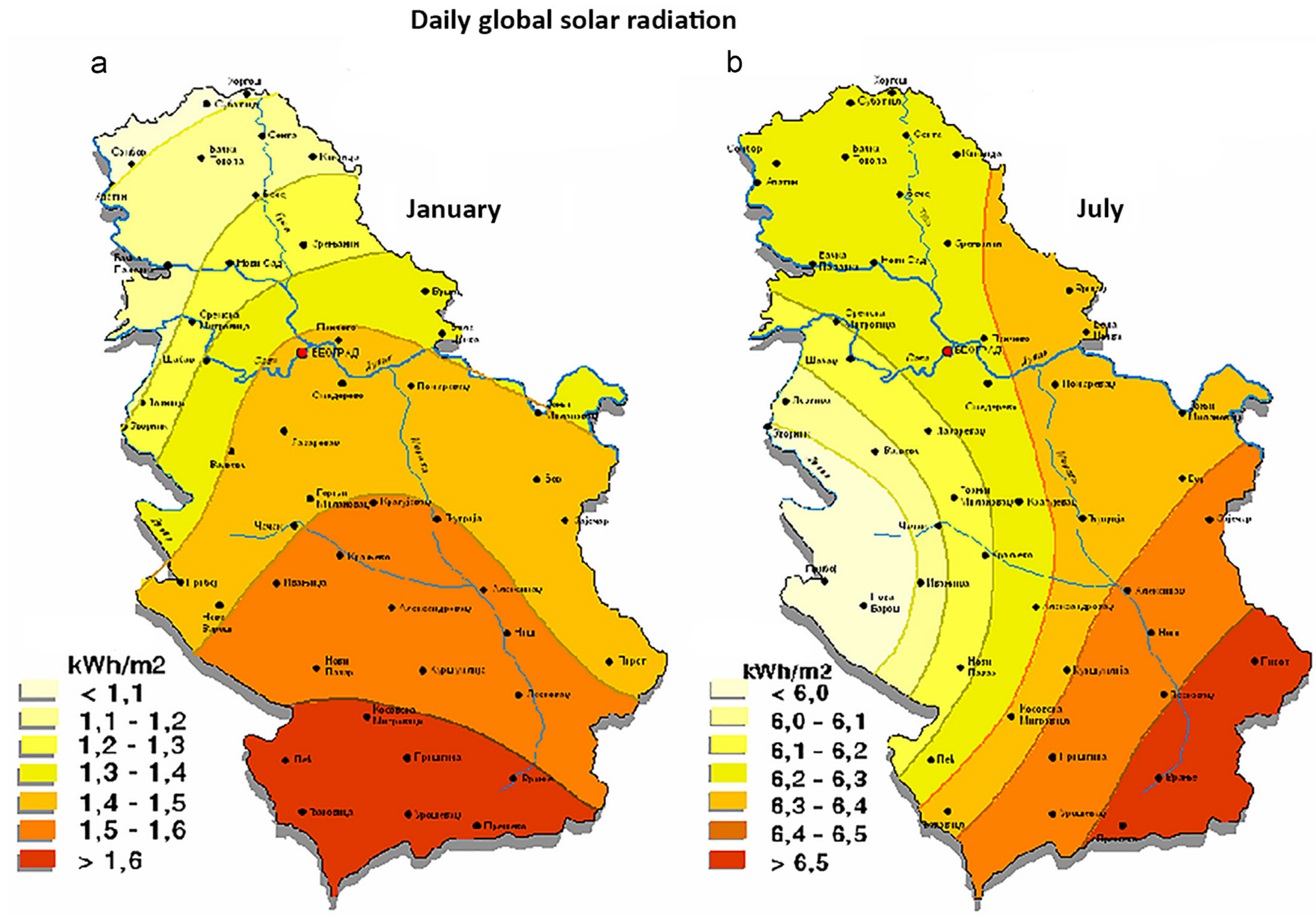


**Fig. 1.** Global solar radiation on a horizontal plane in Serbia [6].

(10.2%), USA (10.1%), France (3.1%), Spain (3.0%) and United Kingdom (2.9%) [1].

The use of solar energy in Serbia is almost negligible, despite the fact that Serbia has a significantly higher number of sunny days than e.g. Germany-the world's largest manufacturer of solar energy [2]. With the annual average of 2300 sunshine hours Serbia's solar radiation intensity is one of the highest in Europe. During January, in the North part of the Republic of Serbia the average solar radiation intensity ranges from 1.1 kW h/m$^2$/day and in the South is up to 1.7 kW h/m$^2$/day (Fig. 1a), and during July, values are 5.9–6.6 kW h/m$^2$/day respectively (Fig. 1b). Consequently, Serbia exhibits favorable conditions for the use of solar radiation and its conversion into the thermal and electrical energy [2–5].

On annual basis, the average value of the solar radiation energy ranges from 1200 kW h/m$^2$ in north-west Serbia to 1550 kW h/m$^2$ in southeast Serbia, while in the central part of the country it is about 1400 kW h/m$^2$ (Fig. 2). Maximum technically usable capacity of potential solar power plants is fixed at 450 MW i.e. 540 GW h per year [8].

Nowadays, two widespread ways of the utilization of solar energy are Photovoltaic (PV) and solar thermal energy collectors. Solar cells and additional components are integral parts of the Photovoltaic system. The first practical conversion of solar radiation into electric energy was demonstrated in 1954 by the use of a p–n junction type solar cell with 6% efficiency [9]. Conversion of solar radiation into thermal energy is performed through a transport medium and/or a moving fluid using solar thermal energy collectors and they can be used for drying the agricultural products and/or heating/cooling applications in combination with the auxiliary heaters for air conditioning of buildings [10].

However, a new trend has emerged that incorporate both methods of energy conversion [11], which can be called photo thermo conversion [12]. The solar energy is converted into electricity and heat with a single device called hybrid photovoltaic thermal collector (PVT) [11].

In Serbia, the solar radiation is used mainly for heating water, and rarely for the production of electricity [4]. There are only some examples of solar systems used by private households and companies, with the aim of reduction of energy costs in the summer part of the year. One of the largest solar power plants in Serbia was built in 2014 in the village of Velesnica in Kladovo municipality (installed capacity of 2 MW, the surface of solar panels 13,600 m$^2$) [13]. In early 2013, 2 MW solar PV power plant located in the village of Matarova in the municipality of Kuršumlija was put into operation. It covers an area of 4 ha, consists of 8500 solar modules. The investment value amounted to € 4 million [7]. 1 MW solar PV power plant was built in the municipality of Kladovo in 2013. It covers the area of 2 ha and consists of 4232 solar modules (the area of each module is 1.6 m$^2$ and individual power of 245 W). The investment value amounted to € 1.6 million [14].

Energy production from solar radiation requires significant initial investments, which makes it less attractive in comparison to other renewable sources. Therefore, a more intensive use of solar energy in Serbia above all will depend on the state's stimulating measures [8].

The aim of this paper is to identify the most suitable location for the installation of solar power plant in Knjaževac municipality, which is located in East Serbia (Fig. 3). The total area of the

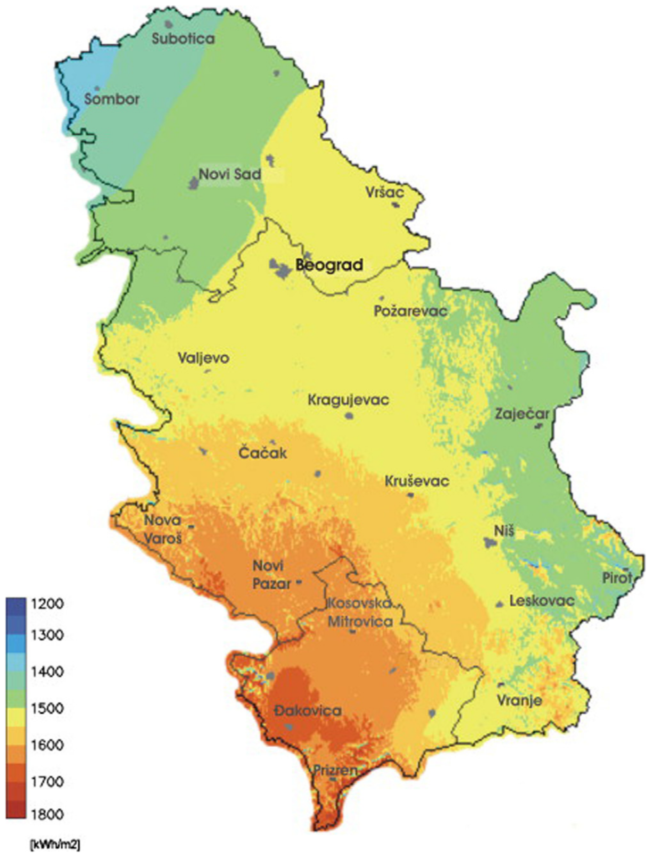


**Fig. 2.** Annual solar radiation intensity [7].

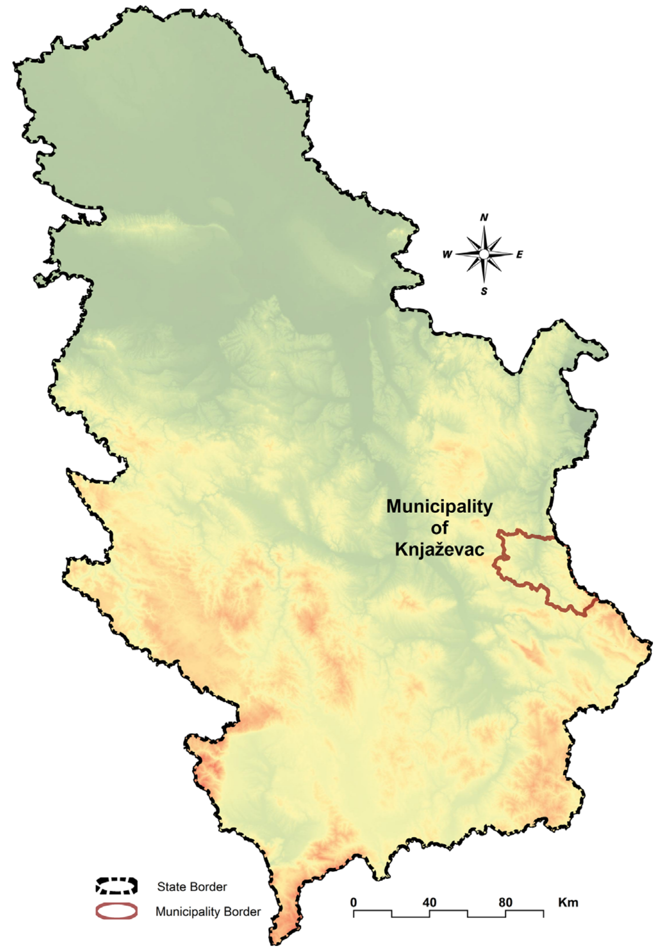


**Fig. 3.** Location of the Municipality Knjaževac.

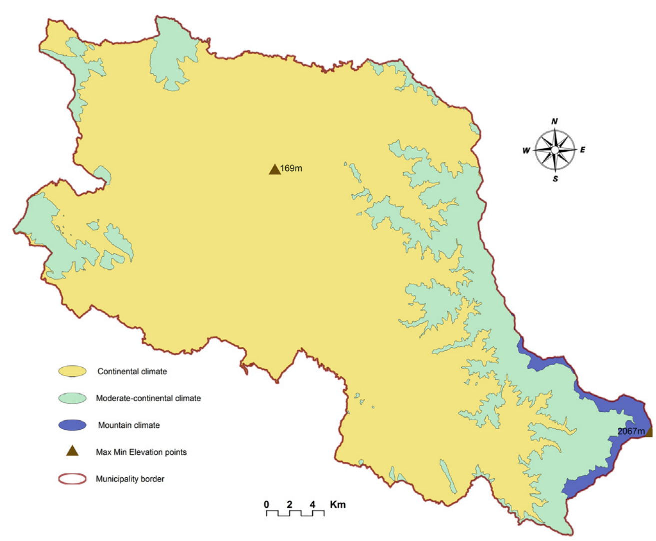


**Fig. 4.** Climate zones of the Municipality of Knjaževac.

municipality, as well as the examined area is 1201.8 km$^2$. The altitude is between 159 m in central part and 2067 m in the southeast part of the municipality (Fig. 4).

Three climate types, continental, moderate-continental and mountain climate are disseminated in Knjazevac municipality (Fig. 4).

Based on the data from the meteorological station of Knjaževac (Table 1), the greatest number of clear days is recorded in summer and autumn, while the largest number of cloudy and foggy days occurs during the winter part of the year. These data indicate that there are solid climatic conditions for the use of solar radiation as an additional source of energy during the year in Knjaževac municipality.

Among different categories of solar radiation models described by Besharat et al. it is concluded that the sunshine-based methods are more accurate than others, but they are limited by the lack of the sunshine records [16]. Due to the lack of the sunshine records, cloud based method was used in this paper.

## 2. Climatic types in Serbia

The continental climate region in which Serbia is located can be divided into the continental climate in the lowlands (up to 800 m), the moderate-continental climate in lower parts of the mountain region (800–1400 m) and the mountain climate on high mountains (over 1400 m).

Air masses formed over Arctic, Siberia, Atlantic Ocean, Mediterranean and the African Sahara have the biggest influence on the climate in this area. A field of high air pressure is formed over these areas. Cold air penetrates mostly from the Siberia but rarely from the Arctic [17]. Vast Panonic lowland is located in the north part of Serbia which is wide open and exposed to the climate influences coming from the north and the east. Continental climate which extends over the Panonic lowland encompasses Vojvodina and its edge until 800 m of height. Extremely hot summers with insufficient humidity, long and harsh winters and mild and short autumns and springs are the main characteristics of continental climate [18]. Mean annual air temperatures in the Panonic area are increasing from the west toward the east and from the north to the south [17]. This climate type extends over the lowest, central part of the Knjaževac municipality and occupies the area of 950.45 km$^2$ (79.08%) (Fig. 4).

**Table 1**
Elements of insolation in the meteorological station Knjaževac (250 m alt.) for the period 2000–2014 [15].

| Month | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean foggy days | 4.29 | 1.54 | 0.69 | 1.00 | 0.69 | 0.31 | 0.15 | 0.38 | 0.69 | 3.91 | 5.64 | 4.00 | 23.29 |
| Mean cloudy days | 14.86 | 11.38 | 10.69 | 8.85 | 6.69 | 4.00 | 2.92 | 3.00 | 7.31 | 9.91 | 13.09 | 15.91 | 108.61 |
| Mean clear days | 3.21 | 3.54 | 5.46 | 4.54 | 5.38 | 8.77 | 10.15 | 14.62 | 8.46 | 8.18 | 4.18 | 2.82 | 79.32 |
| Mean cloudiness | 7.00 | 6.63 | 5.82 | 5.82 | 5.24 | 4.35 | 3.68 | 3.13 | 4.88 | 5.24 | 6.55 | 7.20 | 65.53 |

**Table 2**
Criteria, factors and indicators.

| Criteria | Factors | Indicators | Factor weight type | Factor weight (%) |
|---|---|---|---|---|
| **Climate** | Potential solar radiation (kW h/m$^2$/year) | | Including | 40 |
| | Land surface temperature (°C) | | Including | 10 |
| | Cloudiness | | Including | 30 |
| **Location** | Distance to urban area (km) | | Including | 3 |
| | Distance to road (km) | | Including | 4 |
| **Orography** | Grade (deg) | $<5$<br>5–8.9<br>9–12.9 | Including | 3 |
| | | 13–24.9<br>$>25$ | Excluding | 0 |
| | Aspect | Horizontal<br>East<br>Southeast<br>South<br>Southwest<br>West | Including | 4 |
| | | Nothwest<br>North<br>Northeast | Excluding | 0 |
| **Land use** | Urban area<br>Coniferous forest<br>Deciduous forest<br>Arable land | | Excluding | 0 |
| | Pasture<br>Bare soil | | Including | 6 |

Regions that are located between 800 and 1400 m of altitude belong to moderate-continental climate. It is characterized by moderate hot summers, autumns longer and hotter than springs and cold winters [17]. This climate type extends over the peripheral part of the Knjaževac municipality and occupies the area of 230.42 km$^2$ (19.17%) (Fig. 4).

A mountain climate covers the range over 1400 m of latitude. The main characteristics of this are long, cold and snowy winters and short and chilly summers [18]. This climate type extends over the mountainous, east part of the Knjaževac municipality and occupies the area of 20.936 km$^2$ (1.74%) (Fig. 4).

## 3. Materials and methods

### 3.1. Multi-criteria decision-making method (MCDM)

A different set of information, values, alternatives and preferences are available at the time when the decision must be made. Identifying alternatives, choosing between them and finding the best solution is the main problem for decision-makers [19]. Many different planning processes, including renewable energy planning [20], are using various MCDMs which are following a number of similar steps to fulfill the task: problem definition, identification of alternatives, criteria selection, preparation of the decision matrix and assigning the weights to criteria [21]. There are many different MCDMs that can be used in the analysis of energy policies [22], such as ELECTRE (Elimination Et Choix Traduisant la Realité), PROMETHEE (the Preference Ranking Organization Method for Enrichment Evaluation), AHP (the Analytic Hierarchy Process), etc. [21].

Since the availability of solar radiation at the plain surface is restricted by the clouds and their accompanying weather patterns as the most important atmospheric phenomena [23] and the lack of the sunshine records for the solar radiation models which is designated as the most accurate for insolation calculation [16,24], AHP method with cloudiness data as one of the main limiting factor (Table 2) was used in this study to make a decision where the best locations for solar power plant within the study area are.

Analytic Hierarchy Process (AHP) consists of several steps as shown in Fig. 5. AHP is a theory of measurement for dealing with quantifiable and/or intangible criteria [25]. Main principle of decision making in AHP is that the experience and knowledge of people is at least as valuable as the data they use [26].

#### 3.1.1. Solstice[1]

Assessment of longest and shortest days of Julian year (solstice June 21st and December 21st 2015) was calculated for the central

[1] Solstice is an astronomical phenomenon that occurs twice a year when the sun is on the celestial hemisphere describes the highest or lowest path in relation

point within the coordinates 43.540833 N and 22.331944 E which presents the geometric center of the municipality of Knjaževac. On June 21st, sunrise is at 04 h:49 m:31 s, noon at 12 h:32 m:27 s and sunset at 20 h:15 m:23 s. The daylight lasts for 15 h:25 m:52 s. On December 21st, sunrise is at 08 h:00 m:22 s, noon at 12 h:28 m:37 s and sunset at 16 h:56 m:53 s. The daylight lasts for 08 h:56 m:31 s

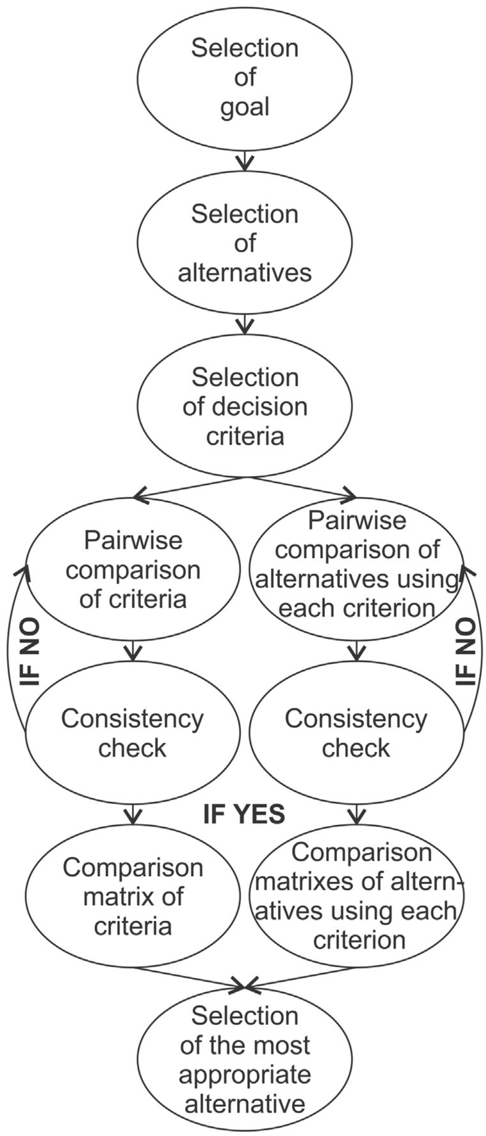


**Fig. 5.** AHP operation mode [26].

[27] (Fig. 6). Time zone used is GMT+1 with Daylight Saving Time (DST) on.

The data (insolation, cloudiness) for two solstices (June 21st and December 21st), the longest and shortest day of the year, are used to calculate the mean value for the year.

Due to the various duration of daylight and different times of sunrise and sunset on the solstices, three periods of time are selected that are within the daylight duration to calculate the potential insolation: 08 h:10 m, 12 h:30 m, 16 h:10 m.

#### 3.1.2. Climate

*3.1.2.1. Solar irradiation.* The amount of mean extra-terrestrial radiation (also called "solar constant") is 1367 W/m$^2$ [28] with slight variations. The solar irradiance can be calculated for each Julian day using following formulae:

$$I_0 = 1367 \cdot [1 + 0.034\cos(\beta) + 0.001\sin(\beta) + 0.0007\cos(2\beta) + 0.0001\sin(2\beta)]\left[\frac{W}{m^2}\right] \quad (1)$$

$$\beta = \frac{2\pi n}{365}[radian] \quad (2)$$

The intensity of radiation on a surface perpendicular to the beam can be calculated using the equation expressing the Beers–Bouguer Law:

$$I = I_0 \cdot p^{\frac{1}{\cos(z)}} \quad (3)$$

where $I$ is radiation intensity on normal surface (perpendicular to the beam) (W/m$^2$), $I_0$ is solar constant (W/m$^2$), $p$ is total transparency coefficient (–) and $z$ is the zenith angle (the angle between the sun beam and the vertical line) [29].

Following equation presents the calculation of the monthly average daily extra-terrestrial solar radiation on a horizontal surface [30]:

$$H_0 = \frac{24 I_0}{\pi}\left[1 + 0.034\cos\left(\frac{360 N_d}{365}\right)\right] \times \left(\cos\phi\cos\delta\sin\omega_{ss} + \frac{2\pi\omega_{ss}}{360}\sin\phi\sin\delta\right) \quad (4)$$

where $I_0$ is the solar constant (1367 W/m$^2$), $\varphi$ is the latitude of the site, $N_d$ is day of the year starting from January 1st (Table 3), and $\delta$ and $\omega_{ss}$ are the monthly mean daily solar declination and sunrise hour angle given, respectively, as [31]:

$$\delta = 23.45\sin\left(360\frac{284 + N_d}{365}\right) \quad (5)$$

Potential insolation was calculated using digital elevation model (DEM) in Insolation module from Geomedia. Three periods of time during the day were chosen for calculating the mean potential insolation (8:10, 12:30 and 16:10) for the day. Time zone

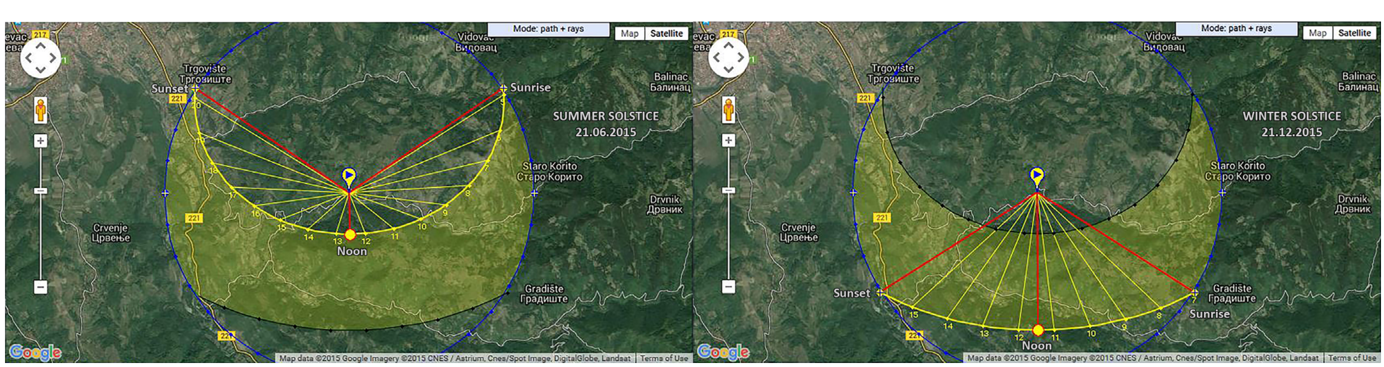


**Fig. 6.** Sun path and sunrays for the central point of the municipality [27].

used is GMT+1 with Daylight Saving Time (DST) on. The difference between daylight saving time was compensated in insolation module setup. Mean annual potential insolation was calculated using the data from shortest and longest day in 2015.

*3.1.2.2. Cloudiness.* Cloudiness is measured in the following manner: the visible part of the sky is divided into 10 equal parts and then estimate how many of the parts are covered by clouds. If the sky is absolutely clear, cloudiness is 0, and if the sky is completely covered with the clouds, cloudiness is 10 [33].

Mean cloudiness was analyzed for corresponding months (June and December) using data from nine meteorological stations located in 20 km radius (Table 4). Data was collected for months June and December for the period of 10 years, starting from 2004 to 2013 (Tables 5 and 6), and then the mean value was calculated (Table 4). Mean values for June and December cloudiness are 4.67 and 7.41 respectively.

The data was interpolated using standard version of geostatistical interpolation kriging, called Ordinary Kriging (Fig. 7). Ordinary Kriging predictions are based on the model [34]:

$$Z(\mathbf{s}) = \mu + \varepsilon'(\mathbf{s}) \tag{6}$$

where $\mu$ is the constant stationary function (global mean) and $\varepsilon'(s)$ is the spatially correlated stochastic part of variation. A value of target variable at some new location can be derived as a weighted

**Table 3**
Recommended average day for each month according to Klein [32].

| Month | Date | $N_d$ | Month | Date | $N_d$ |
|---|---|---|---|---|---|
| January | 17 | 17 | July | 17 | 198 |
| February | 16 | 47 | August | 16 | 228 |
| March | 16 | 75 | September | 15 | 258 |
| April | 15 | 105 | October | 15 | 288 |
| May | 15 | 135 | November | 14 | 318 |
| June | 11 | 162 | December | 10 | 344 |

**Table 4**
Mean cloudiness for the period 2004–2013 [15].

| Longitude E | Latitude N | Station number | Station name | Mean cloudiness June | Mean cloudiness December |
|---|---|---|---|---|---|
| 21 41 | 43 33 | 3834 | Aleksinac | 5.01 | 7.53 |
| 22 19 | 43 13 | 3961 | Bela Palanka | 4.82 | 7.68 |
| 21 09 | 43 55 | 3811 | Bunar | 4.63 | 7.17 |
| 22 17 | 43 53 | 3901 | Zaječar | 4.74 | 7.32 |
| 22 15 | 43 34 | 3931 | Knjaževac | 4.5 | 7.15 |
| 21 54 | 43 20 | 3855 | Niš | 4.38 | 7.28 |
| 22 36 | 43 09 | 3963 | Pirot | 4.36 | 7.42 |
| 21 57 | 43 24 | 3845 | RC Nis | 4.7 | 7.36 |
| 21 51 | 43 39 | 3825 | Sokobanja | 4.78 | 7.44 |

**Table 5**
Average monthly cloudiness in June for the period 2004–2013 [15].

| Station Number | Station Name | Month | June | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Year** | **2013** | **2012** | **2011** | **2010** | **2009** | **2008** | **2007** | **2006** | **2005** | **2004** |
| 3834 | Aleksinac | **Average monthly cloudiness** | 5.3 | 2.8 | 5 | 5.5 | 6.3 | 5 | 4.7 | 5.3 | 4.8 | 5.4 |
| 3961 | Bela Palanka | | 5.9 | 2.2 | 5.9 | 5.4 | 5.8 | 4.9 | 3.4 | 4.8 | 4.3 | 5.6 |
| 3811 | Bunar | | 4.9 | 2.4 | 4.9 | 5.3 | 5.7 | 4.6 | | | | |
| 3901 | Zaječar | | 5 | 3.2 | 4.8 | 5.4 | 5.5 | 4.4 | 3.5 | 5.2 | 4.5 | 5.9 |
| 3931 | Knjaževac | | 5 | 2.1 | 4.9 | 5 | 5.3 | 3.9 | 4.2 | 5.6 | | |
| 3855 | Niš | | 4.9 | 2.2 | 4.4 | 5.2 | 5.3 | 4.3 | 3.6 | 4.7 | 3.9 | 5.3 |
| 3963 | Pirot | | 5.7 | 1.5 | 4.9 | 5.2 | 5.3 | 4.1 | 3.1 | 4.8 | 3.8 | 5.2 |
| 3845 | RC Nis | | 5.5 | 2.3 | 4.7 | 5.5 | 5.5 | 4.5 | 3.7 | 5 | 4.6 | 5.7 |
| 3825 | Sokobanja | | 5.6 | 2.5 | 4.7 | 5.8 | 5.4 | 5 | 3.6 | 4.8 | 4.6 | 5.8 |

**Table 6**
Average monthly cloudiness in December for the period 2004–2013 [15].

| Station Number | Station Name | Month | December | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Year** | **2013** | **2012** | **2011** | **2010** | **2009** | **2008** | **2007** | **2006** | **2005** | **2004** |
| 3834 | Aleksinac | **Average monthly cloudiness** | 5.9 | 7.5 | 7.6 | 7.3 | 7.9 | 7.6 | 8.7 | 6.3 | 8.6 | 7.9 |
| 3961 | Bela Palanka | | 5.8 | 8 | 7.8 | 7.3 | 8.6 | 8.1 | 7.6 | 6.9 | 8.4 | 8.3 |
| 3811 | Bunar | | 5 | 7.3 | 6.9 | 7.2 | 7.9 | 8 | 7.9 | | | |
| 3901 | Zaječar | | 6 | 7.4 | 6.9 | 7 | 8.6 | 7.8 | 7.4 | 6.5 | 8 | 7.6 |
| 3931 | Knjaževac | | 5.8 | 7.3 | 6.9 | 6.9 | 8.6 | 7.9 | 7.6 | 6.2 | | |
| 3855 | Niš | | 5.1 | 7.7 | 6.9 | 6.9 | 8.1 | 7.9 | 7.9 | 5.9 | 8.4 | 8 |
| 3963 | Pirot | | 5.9 | 7.5 | 7.4 | 6.7 | 8.8 | 7.6 | 7.5 | 6 | 8.7 | 8.1 |
| 3845 | RC Nis | | 5.2 | 7.8 | 7.2 | 7.4 | 8.4 | 7.9 | 8.2 | 5.3 | 8.3 | 7.9 |
| 3825 | Sokobanja | | 5.8 | 7.5 | 7.2 | 6.9 | 8.4 | 8.3 | 8 | 6.1 | 8.2 | 8 |

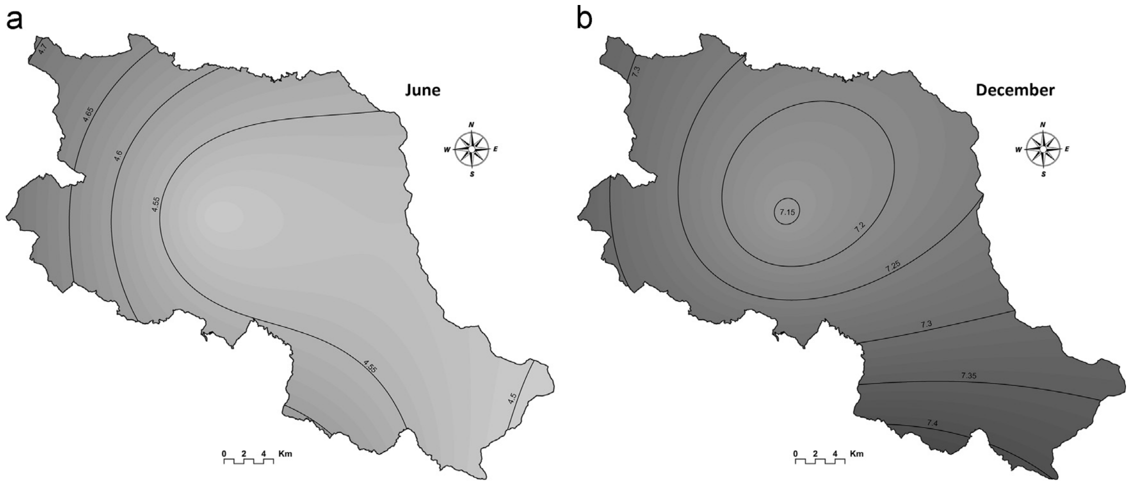


**Fig. 7.** Mean cloudiness in municipality of Knjaževac.

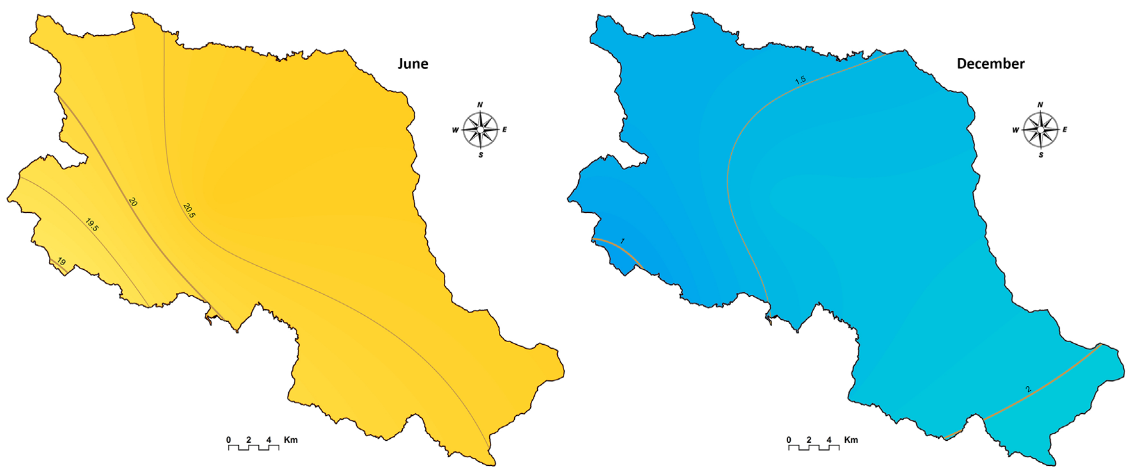


**Fig. 8.** Average temperature of Knjaževac municipality.

**Table 7**
Average monthly temperature in June for the period 2004–2014 [15].

| Station number | Station name | Month | June | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Year | 2014 | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 | 2007 | 2006 | 2005 | 2004 | ΣSt | Mean St |
| 3834 | Aleksinac | Mean monthly temperature (°C) | 20.7 | 21 | 24.7 | 21.8 | 21.2 | 20.9 | 22.6 | 24.1 | 20.7 | 20 | 21.1 | 238.8 | 21.709 |
| 3961 | Bela Palanka | | 18.6 | 19.4 | 22.3 | 19.9 | 19.6 | 19.8 | 20.8 | 21.9 | 19 | 18.2 | 18.9 | 218.4 | 19.855 |
| 3811 | Bunar | | 19.6 | | 22.9 | 20.9 | 20.2 | 19.8 | 21.2 | | | | | 124.6 | 20.767 |
| 3901 | Zaječar | | 19.3 | 20.4 | 22.5 | 20.7 | 20.8 | 20.6 | 21.1 | 22.5 | 19.9 | 19.1 | 19.6 | 226.5 | 20.591 |
| 3931 | Knjaževac | | 19.9 | 20.3 | 23.1 | 20.8 | 20.6 | 20.3 | 21.1 | 22.5 | 19.9 | | | 188.5 | 20.944 |
| 3855 | Niš | | 20.2 | 20.7 | 23.9 | 21.2 | 21 | 20.5 | 22.3 | 23.6 | 20 | 19 | 15 | 227.4 | 20.673 |
| 3963 | Pirot | | 19.8 | 20.4 | 23.9 | 20.7 | 20.3 | 20.2 | 21.3 | 21.9 | 19.3 | 18.8 | 19.4 | 226 | 20.545 |
| 3845 | RC Nis | | 16.3 | 16.4 | 20.4 | 16.9 | 16.9 | 17 | 18.4 | 19.8 | 16 | 15.5 | 16 | 189.6 | 17.236 |
| 3825 | Sokobanja | | 19.8 | 20 | 22.5 | 19.4 | 19.9 | 19.6 | 20.5 | 21.8 | 18.7 | 17.9 | 18.6 | 218.7 | 19.882 |

**Table 8**
Average monthly temperature in December for the period 2004–2014 [15].

| Station number | Station name | Month | December | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Year | 2014 | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 | 2007 | 2006 | 2005 | 2004 | Σ St | Mean St |
| 3834 | Aleksinac | Mean monthly temperature (°C) | 3.4 | 2.5 | 1.7 | 4.6 | 3.1 | 4.9 | 4.5 | 1.1 | 3.5 | 3.8 | 4.2 | 37.3 | 3.391 |
| 3961 | Bela Palanka | | 2.3 | 1.2 | 0.8 | 2.4 | 1.6 | 4.1 | 4.5 | | 1.2 | 3.1 | 2.9 | 24.1 | 2.410 |
| 3811 | Bunar | | 2.3 | 1.2 | 0.7 | 3.3 | 1.7 | 3.1 | 3.4 | 0.2 | | | | 15.9 | 1.988 |
| 3901 | Zaječar | | 0.9 | 0.2 | −1.3 | 3.4 | −0.5 | 1.1 | 1.8 | −0.5 | 2.7 | 2 | 2 | 11.8 | 1.073 |
| 3931 | Knjaževac | | 1.8 | 1.1 | −0.2 | 3.9 | 0.4 | 2.4 | 2.1 | 0.6 | 3.6 | | | 15.7 | 1.744 |
| 3855 | Niš | | 2.8 | 1.7 | 1 | 3.7 | 2.8 | 4.5 | 4.7 | 0.8 | 2.4 | 3.5 | 3.5 | 31.4 | 2.855 |
| 3963 | Pirot | | 2.5 | 2 | 0.9 | 2.8 | 1.4 | 4 | 4 | 0.2 | 1.4 | 3 | 3.1 | 25.3 | 2.300 |
| 3845 | RC Nis | | −0.2 | 0.4 | −1.6 | 1.3 | −0.1 | 1.5 | 0.1 | −2.1 | 1.6 | 0.1 | −0.1 | 0.9 | 0.082 |
| 3825 | Sokobanja | | 0.9 | 1.1 | −0.3 | 3.4 | 1.6 | 3.6 | 2.5 | −0.5 | 1.5 | 2.5 | 2.8 | 19.1 | 1.736 |

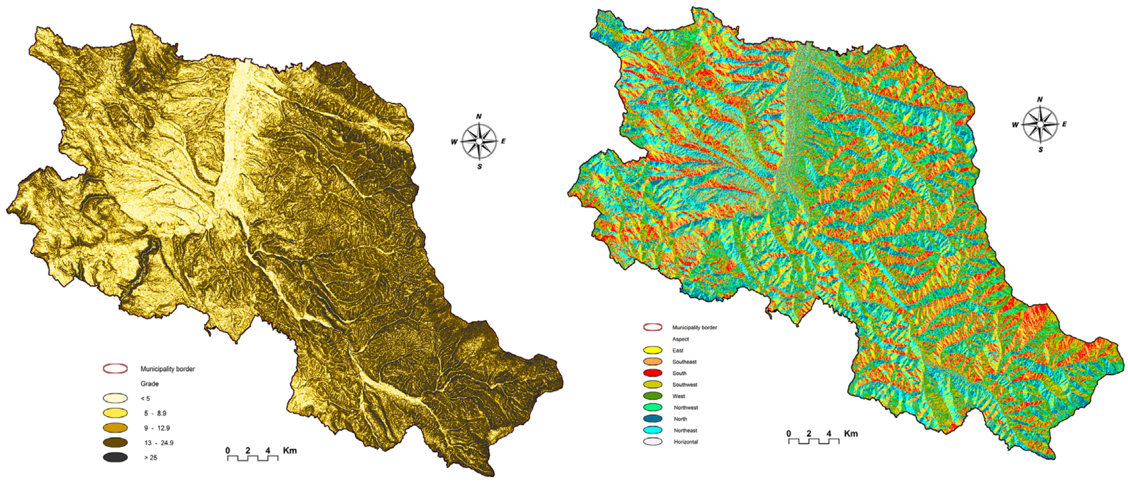


**Fig. 9.** Grade and aspect map of Knjaževac municipalilty.

**Table 9**
Grade categories [39].

| Grade (deg) | Description | Usability |
|---|---|---|
| $<2$ | Plane | Very favorable for construction |
| 2–5 | Slightly sloped terrain | Favorable for construction |
| 5–12 | Sloped terrain | Favorable with landscaping |
| 12–32 | Significantly sloped terrain | Unfavorable, useful for the construction only after major interventions |
| $>32$ | Very steep slopes | Unfavorable for construction |

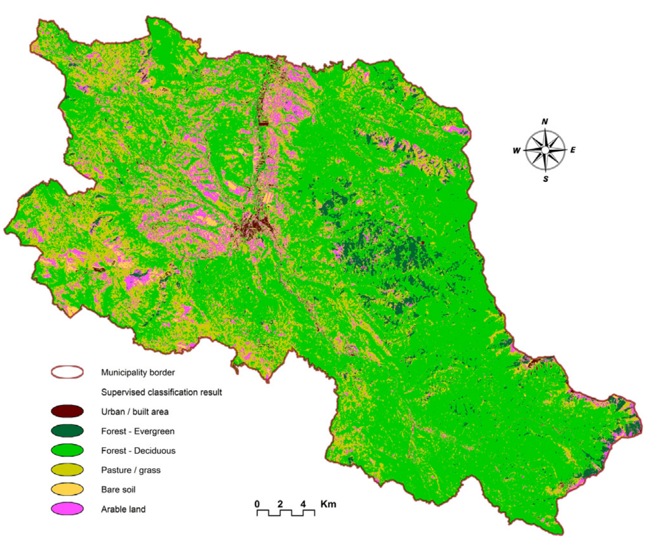


**Fig. 10.** Knjaževac Municipality land use map.

average (spatial prediction) [35]:

$$\hat{z}_{OK}(\mathbf{s}_0) = \sum_{i=1}^{n} w_i(\mathbf{s}_0) \cdot z(\mathbf{s}_i) = \lambda_0^{T} \cdot \mathbf{Z} \tag{7}$$

where $\lambda_0$ is the vector of kriging weights ($w_i$), **z** is the vector of $n$ observations at primary locations.

(*footnote continued*)
to the celestial equator. On that day, the sun at noon (local solar noon) reaches the highest or lowest point in the sky above the horizon.

The amount of insolation was reduced using interpolated cloudiness data.

*3.1.2.3. Temperature.* Temperature data was collected for months June and December for the period of 11 years, starting from 2004 to 2014, and then the mean value was calculated (Tables 7 and 8). Mean temperature values for June and December are 20.25 °C and 1.95 °C respectively.

The data was interpolated using Ordinary Kriging interpolation (Fig. 8).

Due to the lack of meteorological data for mountain area (east and south-east part of municipality) (Fig. 4), interpolated temperature values (Fig. 8) for that area are imprecise and the weighting factor is reduced to a minimum.

### *3.1.3. Orography*

*3.1.3.1. Digital elevation model (DEM).* 30 m ASTER GDEM v2 [36] was used for potential insolation calculation. It was adjusted using digitized elevation points (987 points) from topographic map 1:50,000 [37] and then interpolated [35] to create precise 10 m DEM.

*3.1.3.2. Grade and aspect.* The grade of the field at a point is defined as the angle measured in the vertical level involving the tangent plane to the surface of the field at a given point with the horizontal plane at the same point (Fig. 9) [38].

The aspect of the field represents the largest line orientation inclination for the observed point. It is defined as an orientation angle direction (azimuth) of the biggest drop in the field. It is determined from the north to the direction biggest drop pitch, measured in the clockwise direction (Fig. 9) [38].

The scale of the usability of terrain for the needs of construction is shown in Table 9.

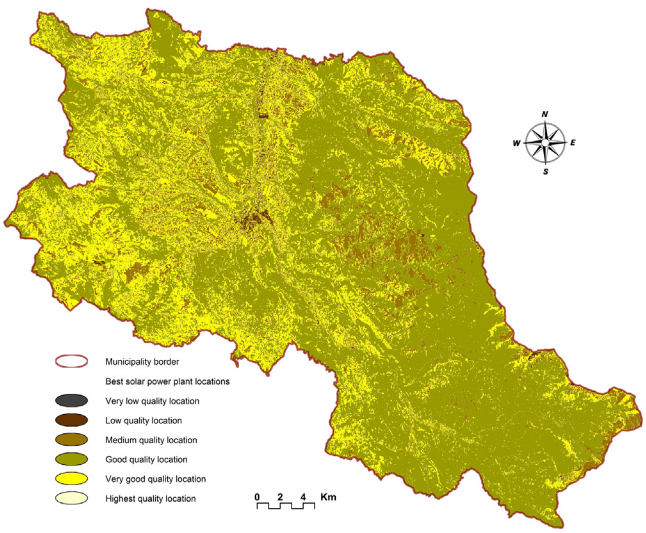


**Fig. 11.** Solar power plants quality locations.

### 3.1.4. Land use cadastre

The possibility to perform multi criteria analysis required the existence of land use cadastre of the municipality. Atmospheric and topographic corrections were applied to satellite data because of the fact, as stated by Okin and Gu [40], that light from the sun must pass twice through the atmosphere and imposes constraints on retrieval of the surface reflectance, particularly with multi-spectral instruments that do not have the spectral resolution to directly estimate atmospheric conditions [40]. Pan Sharpening method was used to enhance the quality of satellite data view (Fig. 11). Minimum distance algorithm [41] from multispectral supervised analysis of Landsat 8 satellite data [42] was performed to classify Land use cadastre. Spatial resolution of the multi-spectral satellite data used for the classification is 30 m and 15 m for panchromatic band used for pan sharpening. Six classes of the land use were separated: *Urban/built area*, *Coniferous forest*, *Deciduous forest*, *Pasture/grass, Bare soil and Arable land* (Fig. 10). The accuracy of the data was compared using large scale topographic maps, Orto photo footage and municipality plans [43].

Three raster maps were used for the final analysis. The first analysis gave the result of approximately “real” insolation where the insolation of the terrain was decreased using cloudiness interpolated data. The other part of multi criteria analysis was to combine two raster data sets, “real” insolation and Land use data set. The focus was on the insolation data greater than 133 W/m$^2$ (mean of the “real” insolation data) where everything below was marked as adverse, and the suitable classes of Land use. Classes

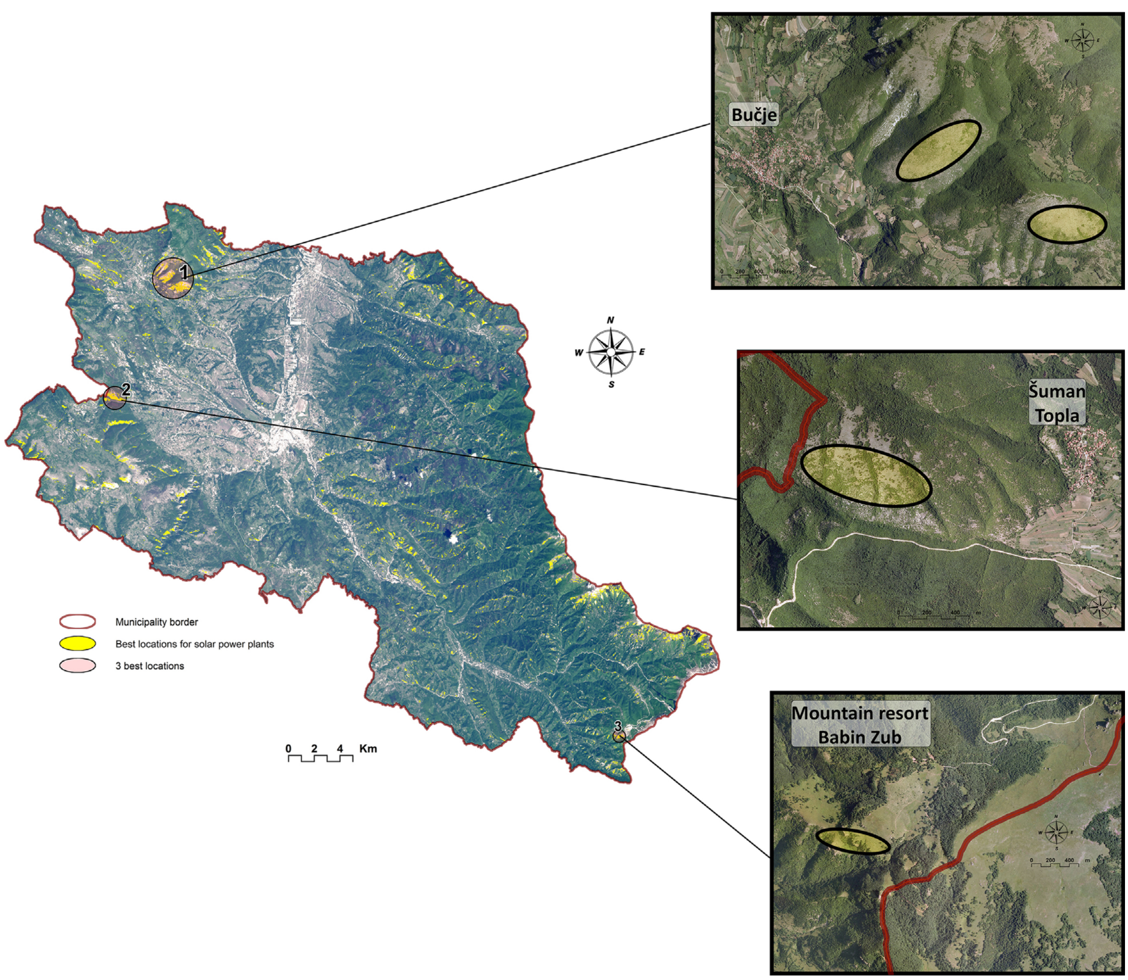


**Fig. 12.** Three best solar power plants locations in Knjaževac Municipality.

Urban area, Coniferous forest and Arable land were marked as adverse, the class Deciduous forest was marked as suitable and classes Bare soil and Pastures were marked as highly suitable where no vast adaptation of terrain for the construction of solar power plant is needed.

After the analysis, the best locations for the solar power plants were presented (Figs. 11 and 12).

## 4. Results and conclusion

The potential insolation data without cloudiness analysis for June 21st and December 21st 2015 are 159.79–738.13 W/m$^2$ (mean 695.0 W/m$^2$) and 0–372.16 W/m$^2$ (mean 120.51 W/m$^2$) per day, respectively. Cloudiness data reduced these values to 72.23–348.27 W/m$^2$ (mean 318.15 W/m$^2$) and 0–276.15 W/m$^2$ (mean 87.86 W/m$^2$) per day, respectively. Annual values (with cloudiness reduction calculated) for the whole area are 0–265.99 W/m$^2$ (mean 132.99 W/m$^2$) per day, which give the annual insolation potential of 48541.35 W/m$^2$.

The result of the analysis is shown in the Figs. 11 and 12. Fig. 11 presents full multi criteria analysis where both calculated insolation raster data and land use raster data with all classes were used. Fig. 12 shows the three best locations by the author's choice. Location 1 is near the regional road and the village Bučje, location 2 is near the regional road and village Šuman Topla and location 3 is chosen because it is located close to the Mountain resort "Babin Zub" which is located in the protected natural area "Stara planina" (Old Mountain).

Considering that June and December are among the cloudiest months of the year, it can be said that the values are of the minimum potential insolation. In practice should be expected a greater amount of the converted energy.

Three zones are chosen in accordance with previously mentioned criteria. For more accurate orography calculation, more precise data of the altitude (DEM) should be used. The satellite images of larger spatial resolution should be used in order to obtain precise classification of land use. Data used in this study only provide a general survey of the solar potential of the given area.

The most suitable solar power plant location studies commonly use insolation potential as the only criterion, while ignoring other significant locational factors: climatic conditions (air temperature and cloudiness), the morphology of the terrain (grade and aspect), land use, proximity to infrastructure and urban areas etc. The multi-criteria analysis in this study includes all mentioned factors in order to determine the real potential for exploitation of solar energy in the municipality of Knjaževac. Synthesis maps of different locations which fulfill the necessary requirements for the installation of solar panels were obtained by the application of the Multi-Criteria Decision Making method (MCDM), Analytic Hierarchy Process (AHP) and GIS and remote sensing analysis of the climate data and multispectral satellite images (Landsat 8).

Although increasing energy consumption creates a great need for finding new energy sources, an obstacle that is significantly restricting and postponing the use of this renewable energy source is low awareness about the possibilities of solar energy consumption in Knjaževac municipality and Serbia as well. Therefore, one of the main goals of this study is to encourage the local authorities, investors, experts and public to take the first steps in the development of this energy sector branch in Knjaževac municipality.

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