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The application of ArcGIS for assessing the potential of solar energy in urban area: The case of Vranje

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Abstract

In order to determine the solar energy potential for a specified location, it is crucial to consider the latitude, altitude, slope, terrain morphology, atmospheric conditions, etc. Such a complex calculation and mapping of solar energy can be done using the ArcGIS geoprocessing tool, named Area Solar Radiation (ASR). By using the ASR tool, supported with the adequate input data, it is possible to calculate the maximum solar radiation energy (irradiation) for a defined area and for a specified time interval. This paper presents a methodology for the application of the ASR tool for the determination of solar energy potential in urban areas. The focus of the research was urban residential areas, where solar panels (for heat and electricity production) can be installed on rooftops. The methodology was tested for the city of Vranje, located in the Southern Region of Serbia. The extraction of the urban area was carried out using the CORINE Land Cover Open Data – the product of the visual interpretation of high-resolution satellite imagery. According to the ASR calculation, the maximum irradiation for a selected part of the urban area is 1,373 kWh/m^2 annually, and the average for a total urban area is 1,227 kWh/m^2, annually. The obtained result can be used as an input for further technical and economic analysis of the cost-effectiveness of the usage of solar energy. The presented methodology can be applied to any other area with an appropriate digital elevation model (DEM), which is the main precondition to ensure the appropriate topographic parameters.

Keywords: Renewable energy, solar potential, GIS, solar mapping.

1. Introduction

Solar radiation is the primary source of energy for many physical and biological processes on Earth and it is one of the basic preconditions for the existence of the living world. In essence, energy received from the Sun is in the form of light and thermal energy. When considering the total impact of the solar radiation, it should in mind that solar radiation is also a precondition for the existence of wind energy, marine energy, and energy in biomass and fossil fuels, captured through photosynthesis.

For the purpose of heating and electricity production, the application of solar panels (solar thermal panels for heating water and PhotoVoltaic (PV) solar panels for electricity production) and the construction of solar thermal power plants is commonly used.

Setting aside a technical characteristic of photovoltaic cells within the solar panels, the amount of electric energy that will be produced depends on many factors. Certainly, one of the most important is the insolation/solar irradiation, defined as the solar radiation energy received from the Sun per unit area of the Earth's surface (kWh/m^2).

The solar irradiation in a specific area depends on latitude (geographic coordinate that specifies the north-south position of a point on the Earth's surface) because it determines the duration of daily solar radiation and annually. Apart from latitude, factors as air temperature, humidity, cloudiness should be also considered.

For the optimal use of solar panels, the morphology of the terrain is also crucial. The variability of morphological factors, such as altitude, slope, and aspect, affects the length of direct solar radiation. In addition, the morphology also affects the level of shading of the area, which certainly reduces the period of direct solar radiation. All the above are essential preconditions for appointing the specific location as a potentially favorable one for panel placement.

When estimating the solar energy potential for the specific location, it is highly recommended to have ground measured data from the meteorological stations. Such data can provide better precision in the evaluation of the solar energy potential.

However, high costs of installation and maintenance of the meteorological stations promoted the development of different methods to estimate the global solar irradiation from the available data. There are several models - available to be used by the public - for creating the solar maps. These models are usually connected with computer software applications, with most of them using ESRI's ArcGIS as their base system (Sarmiento N. et al., 2019). ESRI's ArcGIS can provide the appropriate modeling platform for the estimation of solar radiation energy. Many of the necessary capabilities are now widely accessible from GIS platforms, including abilities to construct or import digital elevation models, to integrate diverse databases for input and output, to access viewshed analysis algorithms that permit assessment of sky obstruction and reflectance etc (Dubayah R., Rich P.M., 1995).

Solar Analyst Tool (SAT) is an extension module of ArcGIS, which derives a solar radiation map based on the input Digital Elevation Model (DEM) (Dubayah R., Rich P. M., 1995). Using the input parameters, such as atmospheric conditions, geographical location, and terrain morphology, the ArcGIS SAT enables the calculation of solar energy potential over a given space and for a specified time interval. The output is a solar map which contains information regarding the quantity of insolation/solar radiation energy for a specified area. Such solar resource calculation and mapping integrated into the SAT is developed by Fu P. and Rich P.M. (in 2000). This tool, which is based on solar geometrical theory, counts incoming solar radiation for each pixel of a DEM. The DEM provides information about the morphology of the area (elevation, slope, and orientation).

In this paper, the developed methodology is tested and analyzed for the urban area of the city of Vranje, located in the southeastern part of Serbia.

2. The state of Renewable Energy Sources in Serbia

Potentials of Renewable Energy Sources (RES) of the Republic of Serbia are significant and estimated at 5.65 Mtoe (Million tonnes of oil equivalent) per annum (Republic of Serbia, 2016). The largest part of the current usage of the RES refers to a traditional way of using biomass and large hydropower plant (Republic of Serbia, 2016).

Other areas in renewable energy, potentially with lower levels of environmental impact, show low levels of development. The utilization of other renewable sources of energy, such as wind, solar, and geothermal, is marginal (Lewis M., 2018).

The estimated potential can have a considerable contribution to the lesser utilization of fossil fuels, as well as the improvement of the environment. The biomass potential amounts to approximately 3.4 Mtoe per year (2.3 Mtoe per year is unused, and 1.1 Mtoe is used), 1.7 Mtoe lies in hydropotential (0.8 Mtoe per year is unused, and 0.9 Mtoe per year is the used hydropotential), 0.2 Mtoe per year in geothermal energy, 0.2 Mtoe per year in geothermal energy, 0.1 Mtoe per year in wind energy, 0.2 Mtoe per year in solar energy and 0.04 Mtoe per year in biodegradable part of waste (Republic of Serbia, 2013).

Total primary energy production from RES in Serbia in 2018 was 2.069 Mtoe (Ministry of Mining and Energy, Republic of Serbia, 2018). In the total domestic production of primary energy from renewable energy sources, the largest share has biomass (56%), then hydropower (38%), wind power (5%), while biogas, solar energy, and geothermal energy participate with 1% in total share (Republic of Serbia, 2018).

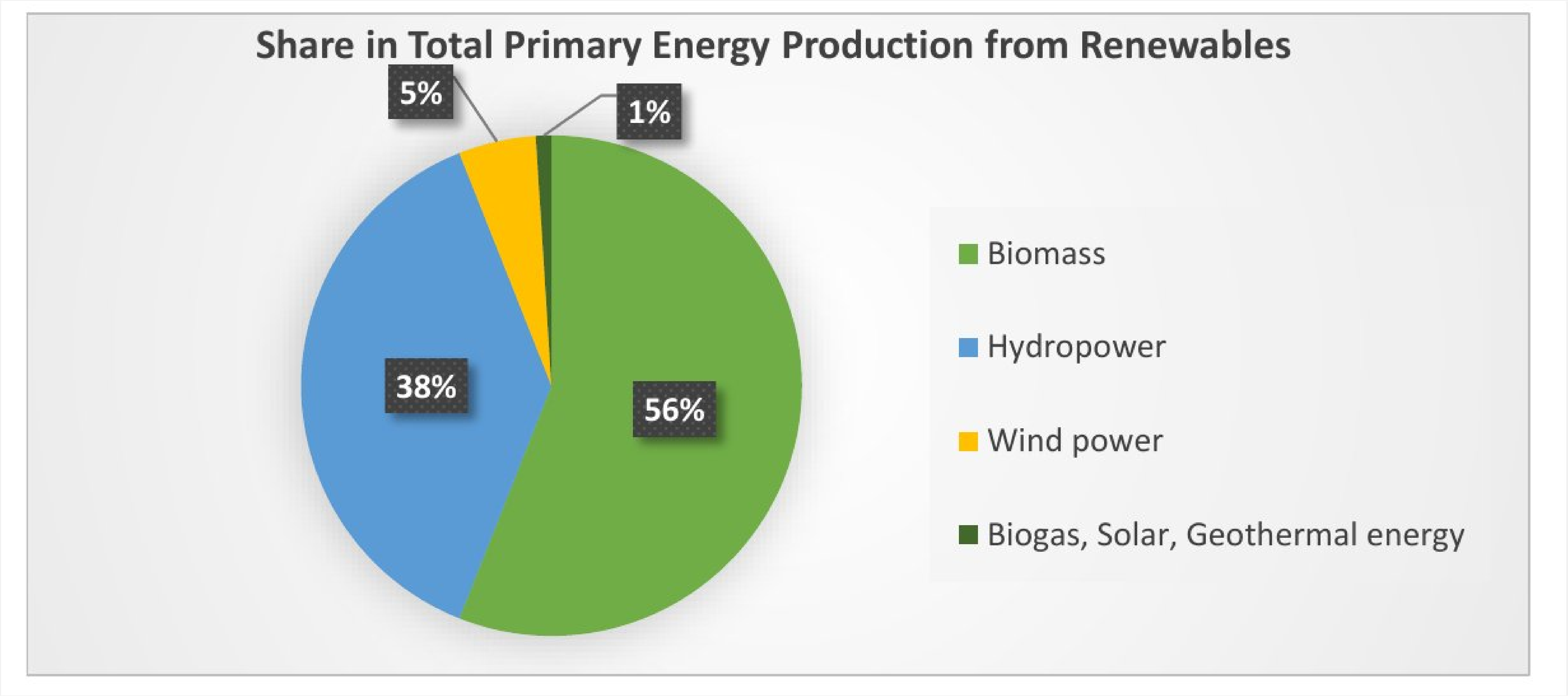


Figure 1: Total production of primary energy from RES in Serbia per energy source (Republic of Serbia, 2018).

3. Potential of solar energy in Serbia

Serbia has an average of 272 sunny days and about 2,300 sunny hours, which is more than the European average (Pavlovic T. et al., 2011).

Annually, the average value of the overall solar radiation energy for the territory of the Republic of Serbia ranges from 1,200 kWh/m^2, in northwest Serbia, to 1,550 kWh/m^2, in southeast Serbia (Pavlovic T. et al., 2011).

For instance, the average value of the annual solar radiation energy in Germany, between 1981 and 2010, fluctuates from approximately 950 kWh/m^2 and 1,260 kWh/m^2 according to a specific location (ISE, 2019). According to the statistics, provided by the International Energy Agency (IEA), solar PV electricity generation in Germany in 2016 was 38,098 GWh (IEA, 2019a). For the same year, solar PV electricity generation in Serbia was 12 GWh (IEA, 2019b)

As can be seen from the comparison with Germany, the discrepancy between the solar potential in Serbia and the utilization of solar radiation energy for electricity generation in Serbia is noticeable. Therefore, it is clear that there is an opportunity for further improvements in using solar energy in Serbia, and consequently, for increasing the share of RES in the gross final consumption of energy.

Existing share of RES in gross final consumption in 20.1%. As a candidate state for future membership of the European Union (EU), Serbia needs to take significant measures towards increasing consumption of RES and more sustainable energy consumption. In accordance with Directive 2009/28/EC of the EU, Serbia adopted the National Action Plan for RES as a framework for promotion of energy generated from RES and set mandatory national goals for share of renewable energy in gross final consumption of energy (27%) as well as the share of energy from RES in transport (10%) by 2020 (Republic of Serbia, 2016).

Considering all the aforementioned, it can be concluded that the installation of new capacities for use of solar energy and its conversion into thermal and electrical energy may contribute to the fulfillment of the goals from Serbia's National Action Plan for RES.

4. Overview of The Solar Analyst Tool

The Solar Analyst Tool (SAT) allows the analysis of the effects of solar radiation. The algorithm which is implemented in the SAT is developed and later upgraded by the authors – Paul Rich and Pinde Fu (1999). As the authors of the SAT point out, the calculation and mapping which are enabled by this tool are very useful for the area for which there is no direct measurement data of solar irradiation/insolation (Fu P., Rich P.M., 2000).

Basically, two types of analysis can be distinguished within the SAT. The first one involves the analysis of a specific area, named "Area Solar Radiation" (ASR), and the second one, is for the analysis of the specific points determined by the x and y coordinates, named "Points Solar Radiation" (PSR) (ESRI, 2019).

In this specific case, the ASR calculation is used for the calculation of the total solar radiation (direct and diffuse) over a time period at the selected geographical area. The calculation is repeated for each pixel of the available DEM. The obtained result of the calculation is given in the form of a raster with values of energy, expressed in Wh/m^2.

5. Data processing

The total amount of solar radiation that reaches the Earth's surface is the sum of direct, diffuse, and the reflected radiation (Figure 2). Generally, direct radiation has the largest share in total solar radiation, and in the second place is diffuse radiation. Reflective radiation has the smallest share in total solar radiation, but it is not negligible in the area with reflective surfaces, such as the area covered with snow. However, the SAT does not include reflected radiation in the calculation, so in this case, the total amount of solar radiation is calculated as the sum of direct and diffuse radiation.

The SAT calculation involves four steps (ESRI, 2019):

1. The calculation of an upward-looking hemispherical viewshed based on topography;
2. Overlay of the viewshed on a direct sun map to estimate direct radiation;
3. Overlay of the viewshed on a diffuse sky map to estimate diffuse radiation;
4. Repeating the process for every location of interest to produce an insolation map.

The SAT generates an upward-looking hemispherical viewshed. A hemispherical viewshed is similar to upward-looking hemispherical (fisheye) photographs, which view the entire sky from the ground up, similar to the view in a planetarium (ESRI, 2019). The hemispherical viewsheds are used to calculate the insolation for each location and produce an accurate insolation map (Fu P., Rich P.M., 2000). Figure 3 shows the layout of the hemispherical viewshed. As it can be seen, such a layout also provides a view of the surrounding topography, where it is possible to observe how topography can prevent direct solar radiation. The resultant viewshed characterizes whether the sky directions are visible (shown in white) or obstructed (shown in gray).

The direct solar radiation originating from each sky direction is calculated using a sun map in the same hemispherical projection as the viewshed. A sun map is a raster representation that displays the sun track or apparent position of the sun as it varies through the hours of the day and through the days of the year. The sun map consists of discrete sectors defined by the sun's position at particular intervals during the day (hours) and time of year (days or months).

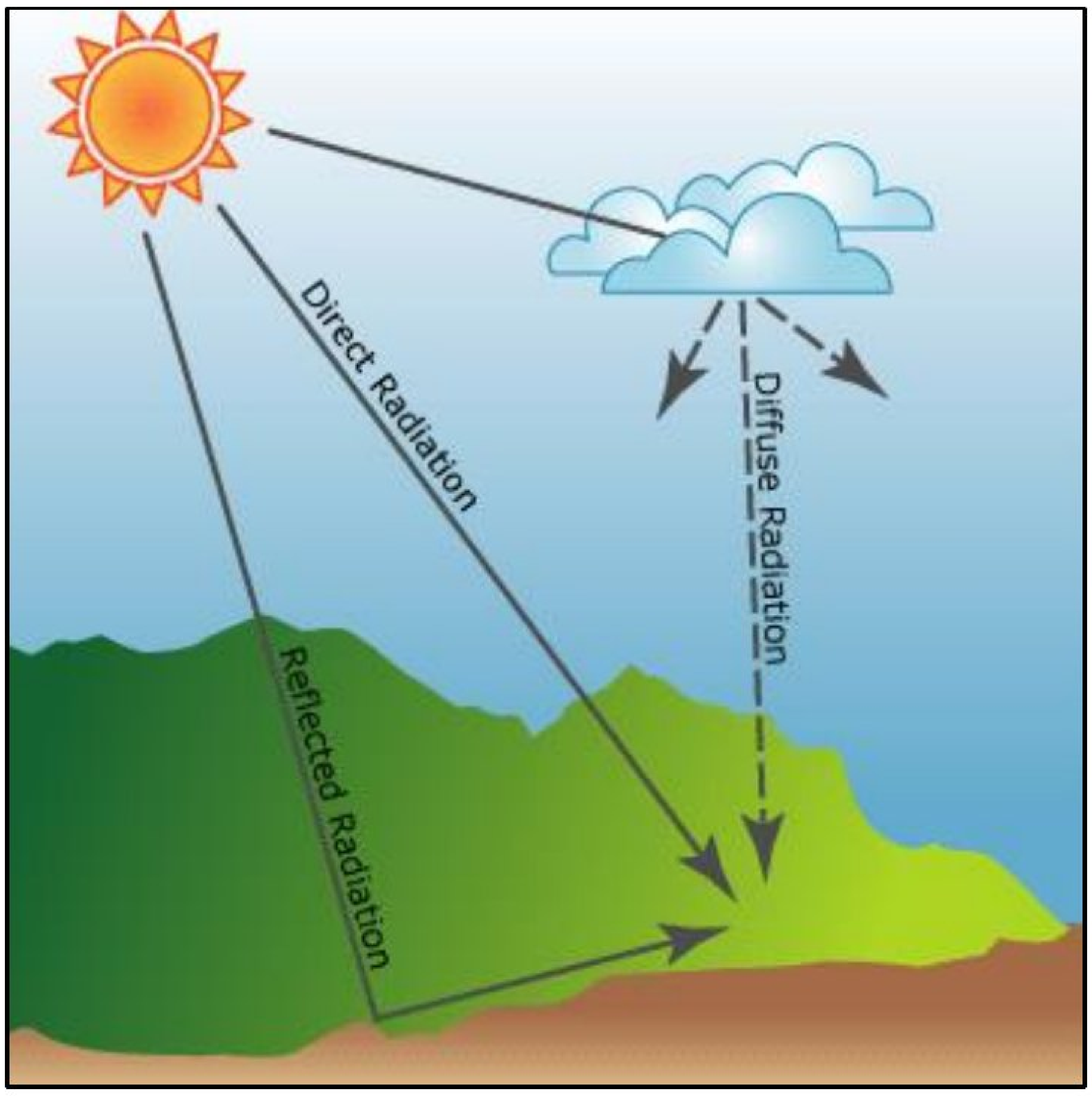


Figure 2: Solar radiation (ESRI, 2019).

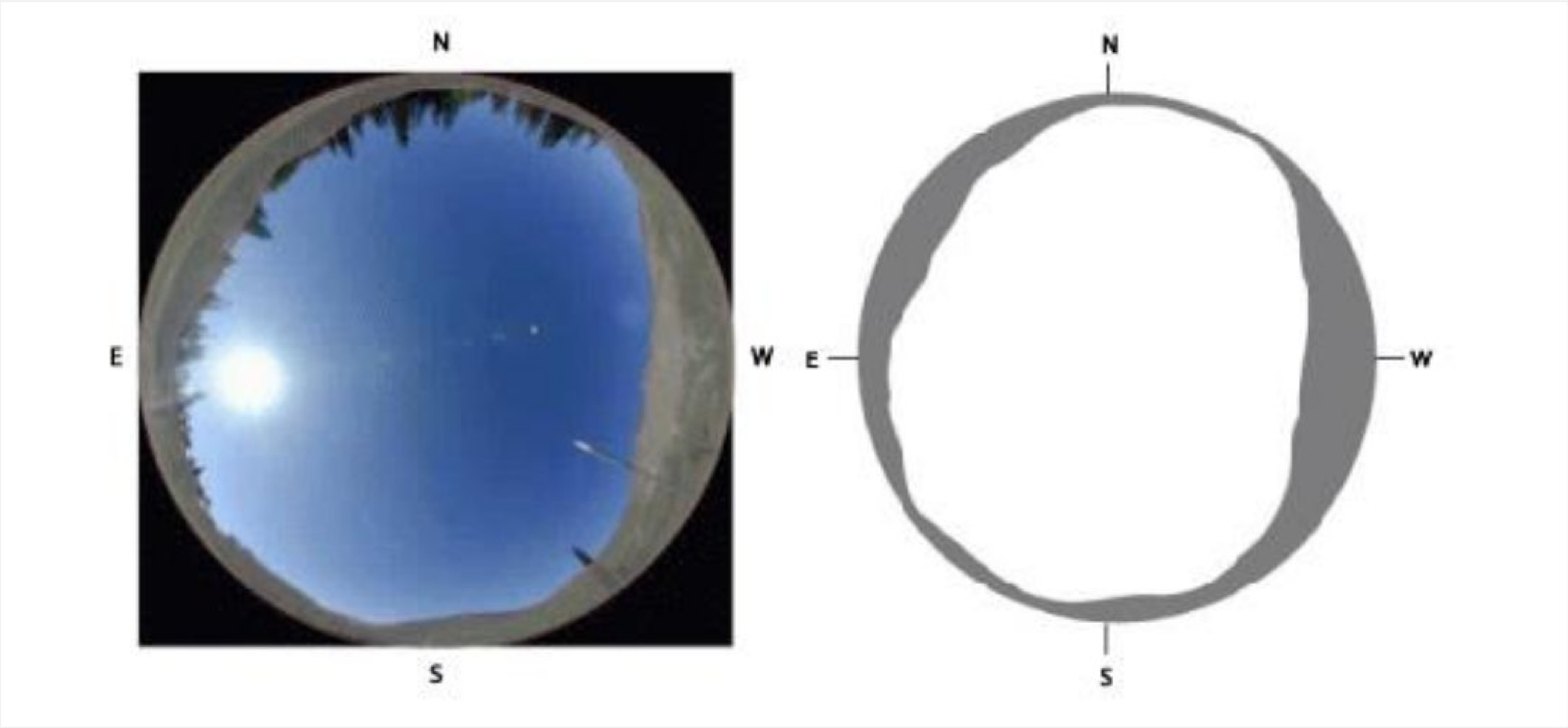


Figure 3: The viewshed of the visible and obstructed sky from a particular point on the surface (ESRI, 2019).

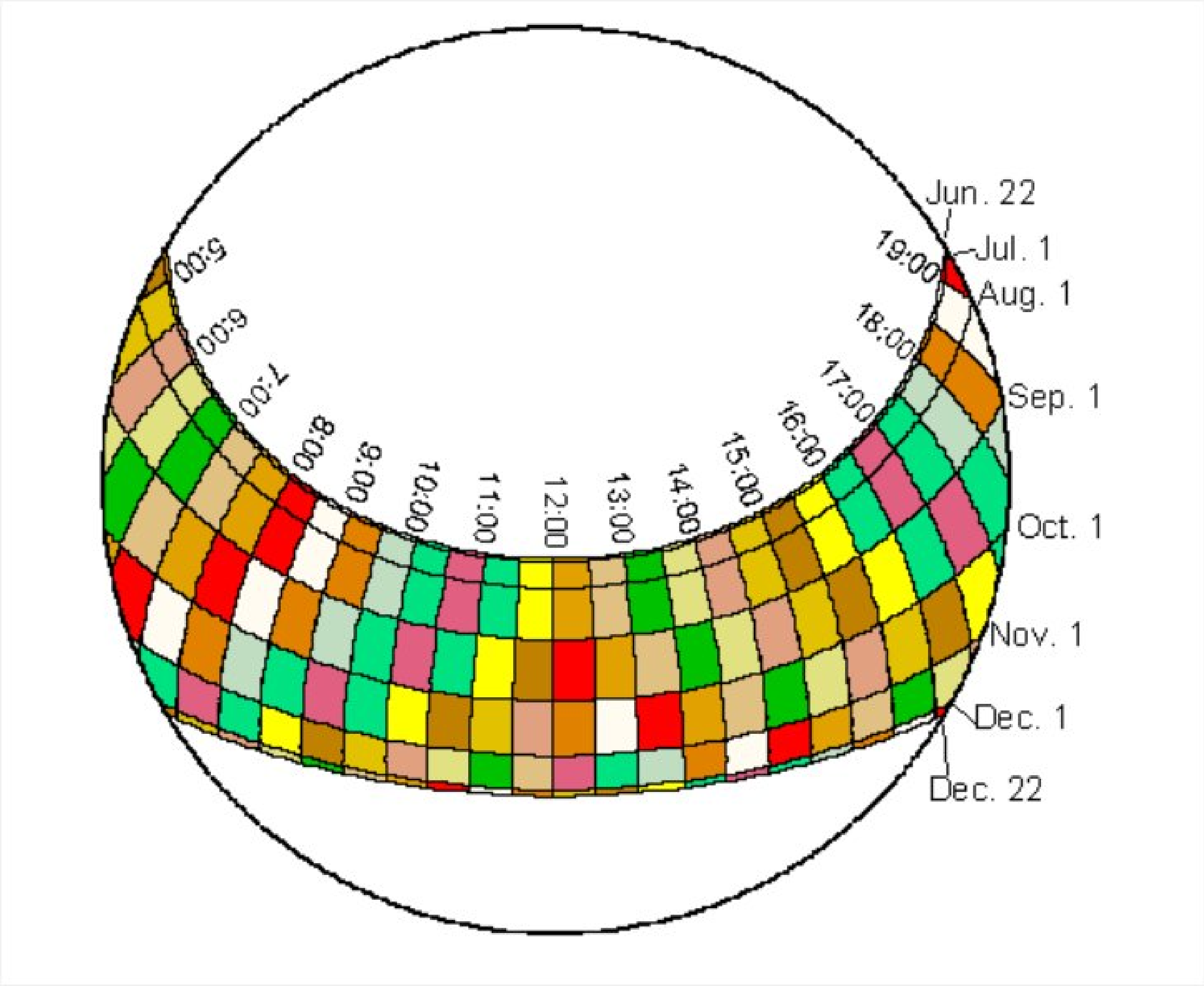


Figure 4: The map of the direct solar radiation (Rich P.M., Fu P., 1999).

Thus, the map of direct solar radiation will represent the Sun's trajectory, which depends on the latitude of the exploration area or points and the specified time interval. Each sector displayed on the map will have a unique value, along with its azimuth and zenith. Figure 4 shows an example of a direct solar radiation map (also called a sun map) that can be found in the literature (Republic of Serbia, 2018). Precisely, this is a map relating to 39° North latitude for the period between the summer and winter solstice (the 22nd of June - the 22nd of December), i.e. between the period when the Sun reaches the highest and lowest point in the sky above the horizon.

Unlike the direct solar radiation, which totally depends on the position and distance of a given area/point relative to the Sun, the diffuse solar radiation can originate from any direction. The diffuse solar radiation is scattered in different directions by clouds, particles in the air, etc.

For this reason, the diffuse solar radiation map (also called sky map) shows a hemispherical view of the entire sky above the observed location, divided into separate sectors with unique diffuse radiation values. The number of sectors depends on the required accuracy in the calculation (ESRI, 2019).

Figure 5 shows a sky map with sky sectors defined by 8 zenith divisions and 16 azimuth divisions. Each color represents a unique sky sector, or portion of the sky, from which diffuse radiation originates (Rich P.M., Fu P., 1999).

In order to obtain a final result, (e.g. the quantity of solar energy for a specific area), the viewshed raster is overlaid with the sun map and sky map rasters to calculate diffuse and direct radiation received from each sky direction. The proportion of visible sky area in each sector is calculated by dividing the number of unobstructed cells by the total number of cells in each sector (ESRI, 2019) (Figure 6).

It is important to note that solar radiation maps and layout of hemispherical viewshed previously shown in this section, are internally used from the SAT and it is not an output of the SAT application. Summarizing the main advantages of the SAT over previously developed models, the authors emphasize the following (Fu P., Rich P.M., 2000):

- Versatile output: calculates direct, diffuse, global radiation, and direct radiation duration, sun maps and sky maps, and viewsheds;
- Simple input: requires only DEM, atmospheric transmissivity, and diffuse proportion;
- Flexibility:
  - calculates insolation for any: i) specified period (instantaneous, daily, monthly, weekly, etc.); ii) region (whole DEM, restricted areas, or point locations);
  - allows the specification of the receiving surface orientation (from DEM, field survey, or orientations of surfaces such as sensors or leaves) and height offsets for ground features;
- Fast and accurate calculation: uses advanced viewshed algorithm for calculations;

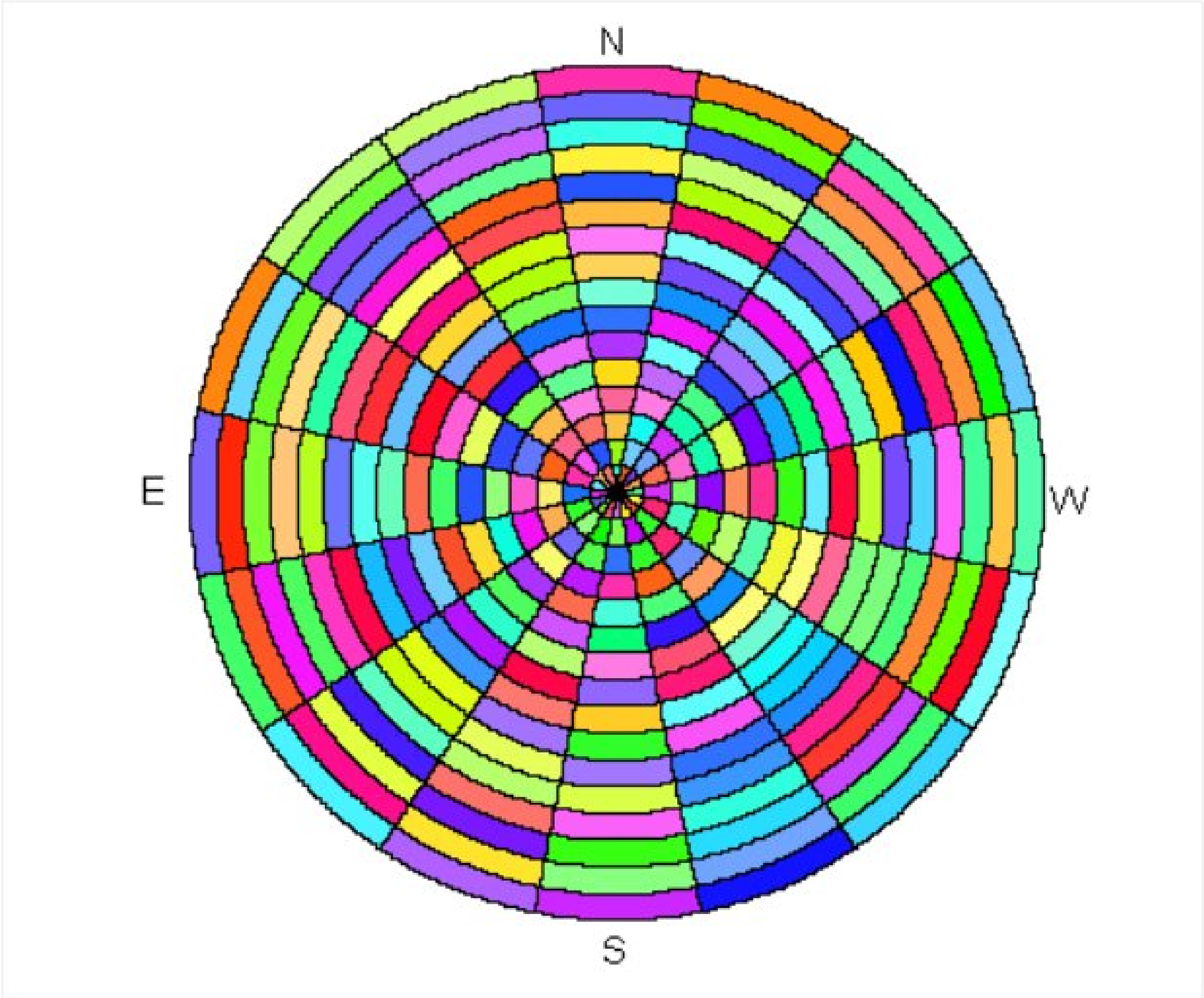


Figure 5: The map of the diffuse solar radiation (Rich P.M., Fu P., 1999).

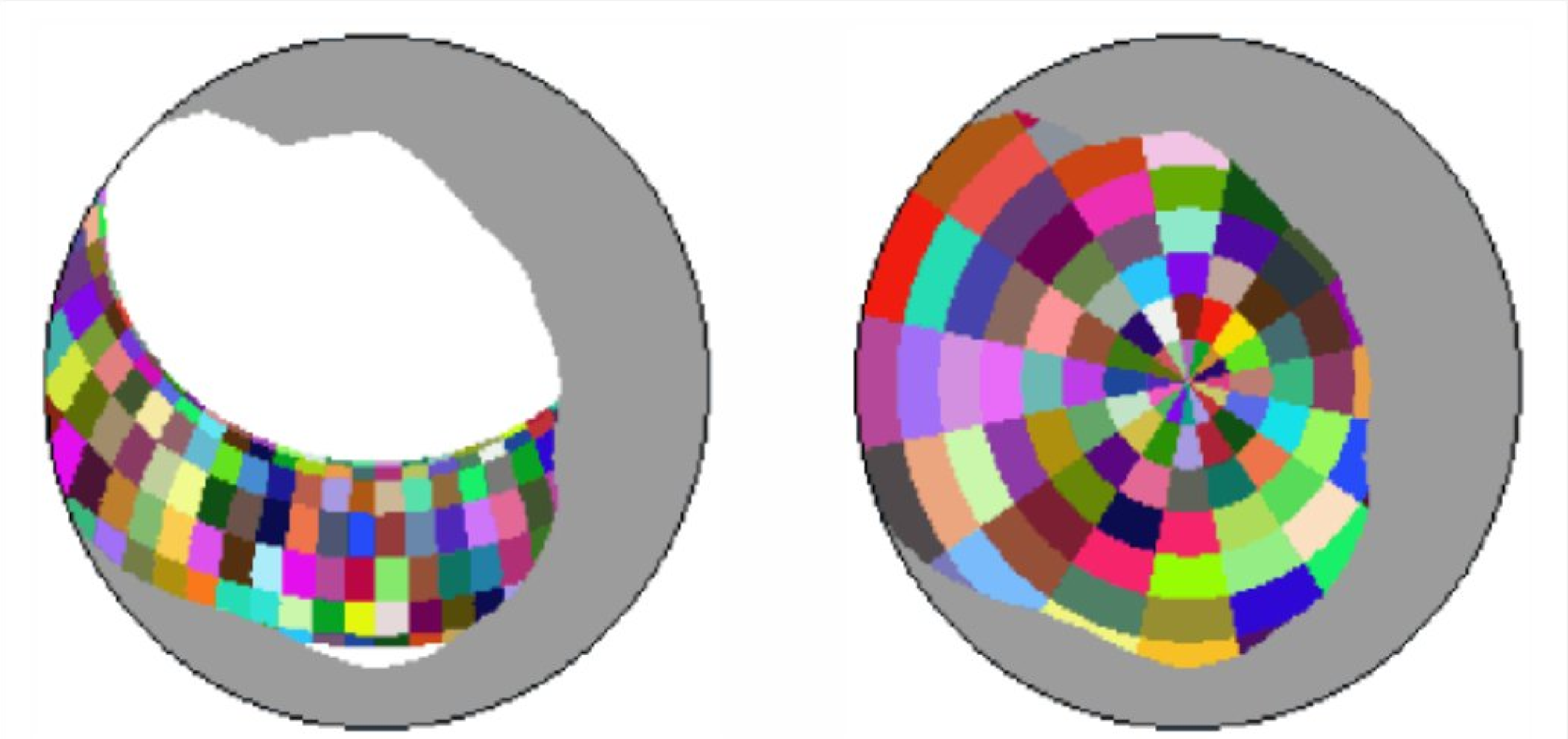


Figure 6: The examples of the overlay of viewshed with maps of direct and diffuse solar radiation (Rich P.M., Fu P., 1999).

- Broad accessibility: the Solar Analyst runs within ArcView and does not require expensive, high–end GIS software;
- User-friendly interface: implements user interface with ArcView Dialog Designer and ArcView Avenue; benefits from ArcView's mapping, query, graphing, & statistics functions;
- Programmable capabilities: improves user efficiency by allowing task automation.

Calculation of solar energy

The total amount of solar radiation, entitled in the SAT as Global radiation ($Global_{tot}$), is calculated as the sum of direct (Dir_{tot}) and diffuse (Dif_{tot}) radiation of all sun map (map of direct solar radiation) and sky map (map of diffuse solar radiation) sectors, respectively (Fu P., Rich P.M., 2000):

$$Global_{tot} = Dir_{tot} + Dif_{tot} \quad (1)$$

Direct solar radiation

Total direct insolation (Dir_{tot}) for a given location is the sum of the direct insolation ($Dir_{\theta,\alpha}$) from all sun map sectors respectively (Fu P., Rich P.M., 2000):

$$Dir_{tot} = \Sigma\ Dir_{\theta,\alpha} \quad (2)$$

The direct insolation from the sun map sector ($Dir_{\theta,\alpha}$), with a centroid at zenith angle (θ) and azimuth angle (α), is calculated using the following equation (3):

$$Dir_{\theta,\alpha} = S_{Const} * \beta^{m(\theta)} * SunDur_{\theta,\alpha} * SunGap_{\theta,\alpha} * \cos(AngIn_{\theta,\alpha}) \quad (3)$$

where:

$\mathbf{S_{Const}}$ = The solar flux outside the atmosphere at the mean earth-sun distance, known as solar constant. The solar constant used in the analysis is 1367 W/m^2. This is consistent with the World Radiation Center (WRC) solar constant;

$\boldsymbol{\beta}$ = The transmissivity of the atmosphere (averaged over all wavelengths) for the shortest path (in the direction of the zenith);

$\mathbf{m(\theta)}$ = The relative optical path length, measured as a proportion relative to the zenith path length;

$\mathbf{SunDur_{\theta,\alpha}}$ = The time duration represented by the sky sector. For most sectors, it is equal to the day interval (for example, a month) multiplied by the hour interval (for example, a half-hour (0.5)). For partial sectors (near the horizon), the duration is calculated using spherical geometry;

$\mathbf{SunGap_{\theta,\alpha}}$ = The gap fraction for the sun map sector;

$\mathbf{AngIn_{\theta,\alpha}}$ = The angle of incidence between the centroid of the sky sector and the axis normal to the surface (see equation 4 below).

Relative optical length, $\mathbf{m(\theta)}$, is determined by the solar zenith angle and elevation above sea level. For zenith angles less than 80°, it can be calculated using the following equation (ESRI, 2019):

$$m(\theta) = EXP(-0.000118 * Elev - 1.638*10^{-9} * Elev^2) / \cos(\theta) \quad (4)$$

where:

- $\boldsymbol{\theta}$ = The solar zenith angle;
- **Elev** = The elevation above sea level in meters.

The effect of surface orientation is taken into account by multiplying by the cosine of the angle of incidence. The angle of incidence ($AngInSky_{\theta,\alpha}$) between the intercepting surface and a given sky sector with a centroid at zenith angle and azimuth angle is calculated using the following equation (ESRI, 2019):

$$AngIn_{\theta,\alpha} = acos(\ Cos(\theta) * Cos(G_z) + Sin(\theta) * Sin(G_z) * Cos(\alpha - G_a)) \quad (5)$$

where:

$\mathbf{G_z}$ = The surface zenith angle;

Note that for zenith angles greater than 80°, refraction is important;

$\mathbf{G_a}$ = The surface azimuth angle.

Diffuse radiation calculation

For each sky sector, the diffuse radiation at its centroid (**Dif**) is calculated, integrated over the time interval, and corrected by the gap fraction and angle of incidence using the following equation (Fu P., Rich P.M., 2000):

$$Dif_{\theta,\alpha} = R_{glb} * P_{dif} * Dur * SkyGap_{\theta,\alpha} * Weight_{\theta,\alpha} * \cos(AngIn_{\theta,\alpha}) \quad (6)$$

where:

$\mathbf{R_{glb}}$ = The global normal radiation (see equation 6 below).

$\mathbf{P_{dif}}$ = The proportion of global normal radiation flux that is diffused. Typically, it is approximately 0.2 for very clear sky conditions and 0.7 for very cloudy sky conditions.

Dur = The time interval for analysis.

SkyGap$_{\theta,\alpha}$ = The gap fraction (proportion of visible sky) for the sky sector.

Weight$_{\theta,\alpha}$ = The proportion of diffuse radiation originating in a given sky sector relative to all sectors (see equations 7 and 8 below).

AngIn$_{\theta,\alpha}$ = The angle of incidence between the centroid of the sky sector and the intercepting surface.

The global normal radiation (**R**$_{\mathbf{glb}}$) can be calculated by summing the direct radiation from every sector (including obstructed sectors) without correction for the angle of incidence, then correcting for proportion of direct radiation, which equals **1-P**$_{\mathbf{dif}}$ (ESRI, 2019):

$R_{glb} = (S_{Const}\ \Sigma(\beta^{m(\theta)})) / (1 - P_{dif}) \quad (7)$

For the uniform sky diffuse model, **Weight**$_{\theta,\alpha}$ is calculated as follows (ESRI, 2019):

$Weight_{\theta,\alpha} = (\cos\theta_2 - \cos\theta_1) / Div_{azi}$

where:

θ_1 and θ_2 = The bounding zenith angles of the sky sector.

Div_{azi} = The number of azimuthal divisions in the sky map.

For the standard overcast sky model, **Weight**$_{\theta,\alpha}$ is calculated as follows:

$Weight_{\theta,\alpha} = (2\cos\theta_2 + \cos 2\theta_2 - 2\cos\theta_1 - \cos 2\theta_1) / 4 * Div_{azi} \quad (9)$

Total diffuse solar radiation for the location (Dif_{tot}) is calculated as the sum of the diffuse solar radiation (Dif) from all the sky map sectors (3):

$Dif_{tot} = \Sigma\ Dif_{\theta,\alpha} \quad (10)$

Case of Vranje

Vranje is the administrative center of Pcinja district. The DMS coordinates of Vranje are **42°33'5" N 21°54'1" E.** The city is located in the southeastern part of Serbia (Figure 7). The total area of Vranje is 860 km^2, and according to the estimation of the Statistical Office of Republic of Serbia from 2017, the population of the city administrative area is 80,961 people (SORS, 2018).

Vranje is selected for the case study based on available literature on solar energy potential in Serbia, where the southeastern part of Serbia is pointed out as an area with good potential for the usage of solar energy (University of Belgrade, 2004; Stamenkovic Lj., 2009).

The average daily solar radiation energy for a flat surface during winter ranges between 1.1 kWh / m^2 in Northern Serbia and 1.7 kWh / m^2 in Southern Serbia, and in the summer between 5.4 kWh / m^2 in Northern Serbia and 6.9 kWh / m^2 in Southern Serbia (University of Belgrade, 2004). It should be noted that the data were obtained based on data measured at meteorological stations University of Belgrade, 2004). Figure 8 shows two maps with the average daily energy of solar radiation on a horizontal surface. The map on the left shows the average daily energy of solar radiation in January and the map on the right shows the average daily energy of solar radiation in July. The black-colored circle shows the position of Vranje on the map of Serbia.

In this case study, the focus is on the estimation of solar radiation energy in urban area of the city for the reason that most people live in there and also, there is a large number of buildings that are potentially suitable for installation of solar panels.

For the purpose of representing the topographic surface (three-dimensional terrain) of the urban area of the city of Vranje, a Digital Elevation Model (DEM) is used. The DEM can be represented as a raster. Raster data is made up of pixels (or cells), and each pixel has an associated value. In case of the DEM, each cell has a value corresponding to its elevation (PBC GIS, 2019). For the generation of the DEM generally data issued from different sources can be used (Taud H. et al., 1999):

- Contour lines (from existing maps),
- Photogrammetric (aerial photography or digital satellite imagery),
- Field data.

In this work, the DEM which is generated from the contour lines and its resolution is 10 m is used. This DEM originates from the University of Belgrade, (Faculty of Forestry, 2018).

For the optimal usage of the Solar Analyst Tool, it is important to point out that the resolution of a DEM affects the results of the estimation of solar energy potential.

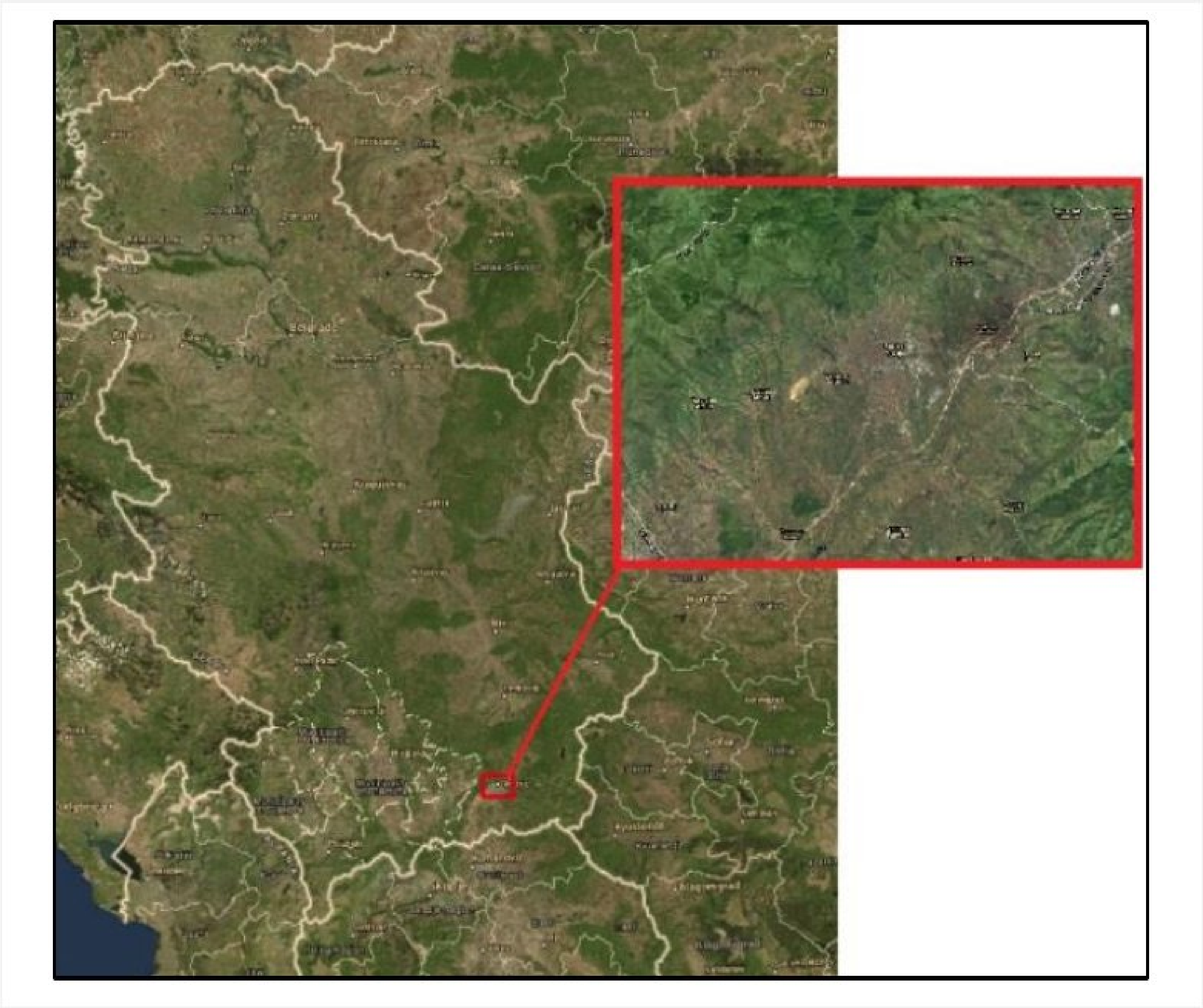


Figure 7: The geographical position of the city of Vranje.

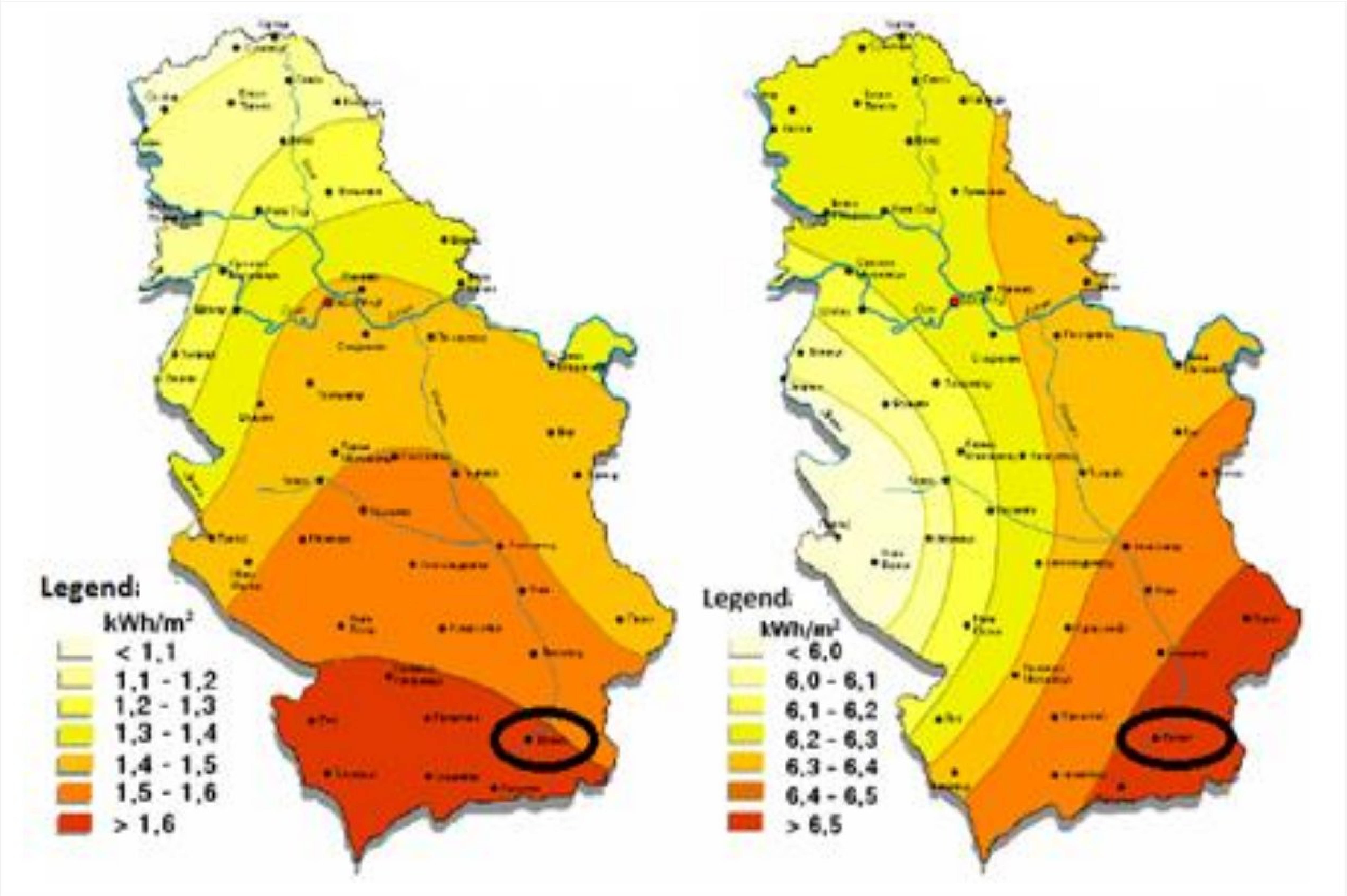


Figure 8: Average daily solar irradiation to the horizontal surface for January (left) and July (right) (15) (University of Belgrade, 2004).

The higher resolution provided, the better information regarding the suitability of the location for the installation of solar panels it is.

The extraction of the urban area of the city of Vranje is carried out using the CORINE Land Cover Open Data – the product of the visual interpretation of high-resolution satellite imagery (Copernicus land Monitoring Service, 2019a). Corine means “coordination of information on the environment” and it is a prototype project working on many different environmental issues. As described on the website, Copernicus Land Monitoring Service (CLMS) provides geographical information on the land cover to a broad range of users in the field of environmental terrestrial applications (Copernicus land Monitoring Service, 2019b).

Data from CORINE Land Cover (CLC) is generated by the processing of high-resolution satellite images and they provide information about land cover changes in the major part of Europe. Polygonal entities represent a state of land cover differentiated in 44 classes, divided into a 3-level hierarchical classification system (Stojkovic S., 2017). The COPERNICUS website includes CLC datasets for different years with the corresponding land cover changes (Copernicus land Monitoring Service, 2019a).

Regarding the object of this study, using the ArcGIS software (ArcMap) it is possible to extract the urban area from CLC, originally defined as a class of Urban fabric, which is consisting of the next subclasses (20):

- No. 111 - Continuous urban fabric, and
- No. 112 - Discontinuous urban fabric, which is the object of interest for this case study.

In the case of Vranje, it possible to extract only the class No. 112 – Discontinuous urban fabric, showed in Figure 9.

Using ArcMap's option **"Select Features"** it is possible to export the selected class of the land cover and make the new shape file which contains only the urban area of Vranje. For clipping the DEM to the dimension of the urban area of Vranje, it is used the Clip Tool in ArcMap. In the Clip Tool in the field named **"Input Raster", it is necessary to load the specified DEM from the Introduction.** After that, in the field named **"Output Extent",** the shape file which contains the urban area of Vranje is loaded.

The Clipping tool will clip the inserted DEM for the required area, as it can be seen in Figure 10 below. When the DEM of the urban area of Vranje is defined, the next step is the implementation of the tool Area Solar Radiation. The ASR is used to calculate the total insolation/solar radiation energy over a selected period of time for the urban area of Vranje.

Required data to complete the calculation includes the following:

- DEM;
- **Latitude for the site area** - based on input DEM. The analysis is designed only for local landscape scales, so it is generally acceptable to use one latitude value for the whole DEM.
- Sky size - the resolution of the viewshed, sky map, and sun map rasters that are used in the radiation calculations (units: cells per side). These are upward-looking, hemispherical raster representations of the sky and do not have a geographic coordinate system. These rasters are square (equal number of rows and columns). The recommended sky dimension value for a daily interval greater than 14 days is 200 (ESRI, 2019).
- Time configuration - there are 4 options (ESRI, 2019).
  - Calculation of solar radiation energy for winter and summer solstice,
  - Calculation within one day,
  - Multi-day,
  - Within one year.

  In this particular case, the calculation is made for the whole year and for July and December.
- Day interval - data required to analyze the position of the Sun over time. The auto-set interval is 14 days. The interval can be set to be shorter, but it is not recommended to be shorter than 3 days since the Sun's trajectory overlaps at shorter intervals (ESRI, 2019).

- Hour interval - Time interval through the day (units: hours) used for calculation of sky sectors for sun maps. In this case, the accepted default value is -0.5.
- Topography parameters:
  - Z factor - used to adjust the calculation in cases where the units of measurement for the z coordinate are not the same as for the x, y coordinates. If the x, y units, and z units are in the same units of measure, the z-factor is 1. This is the default.
  - Slope and aspect - The slope and aspect rasters are calculated from the input surface raster. This is the default.
  - **Number of azimuth directions** - Valid values must be multiples of 8 (8, 16, 24, 32, and so on). The recommended number for complex topography, such as in the case of the topography of the city of Vranje, is 32.

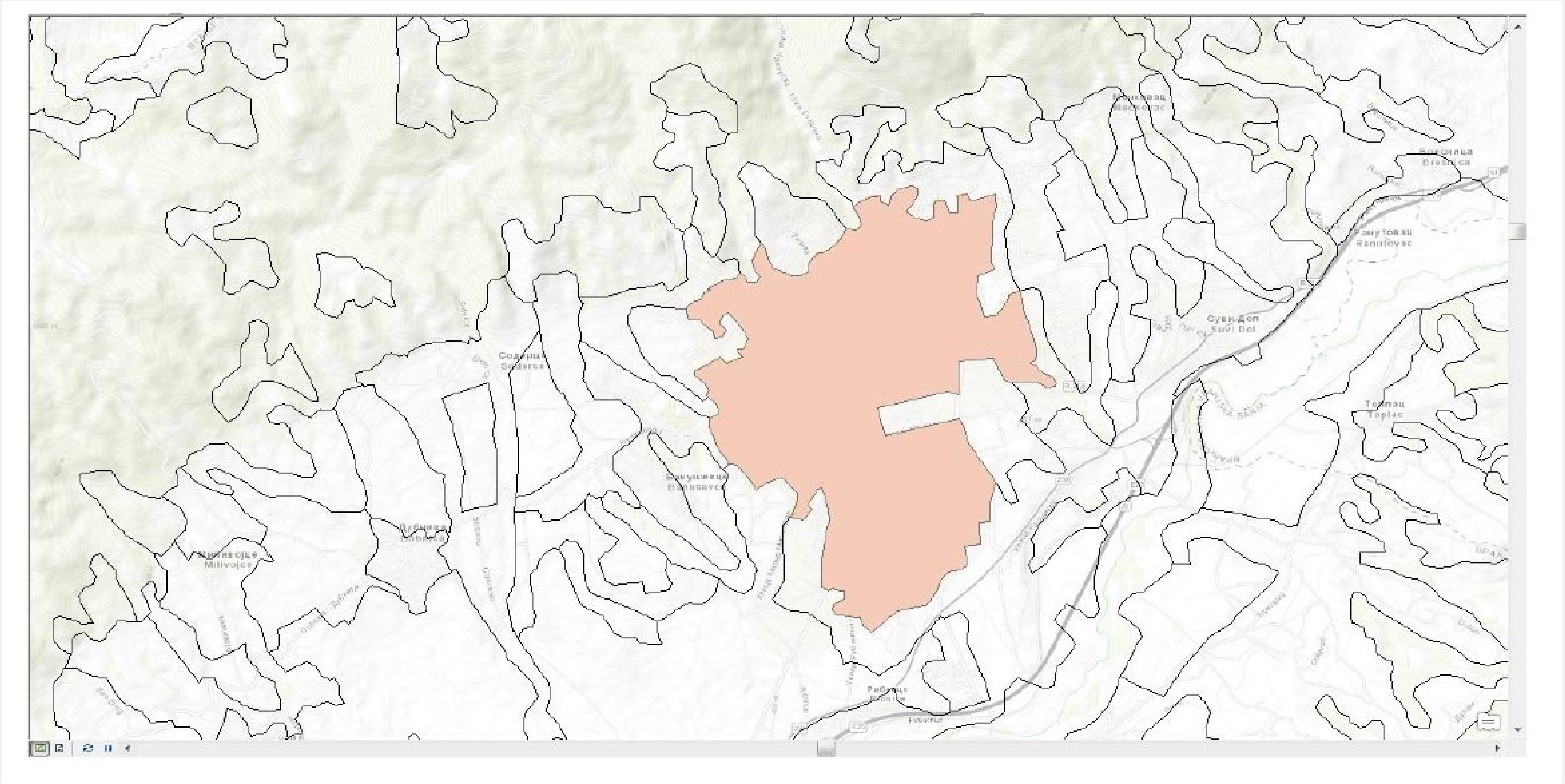


Figure 9 : The Urban area of Vranje in Corine Land Cover (CLC) Open Data.

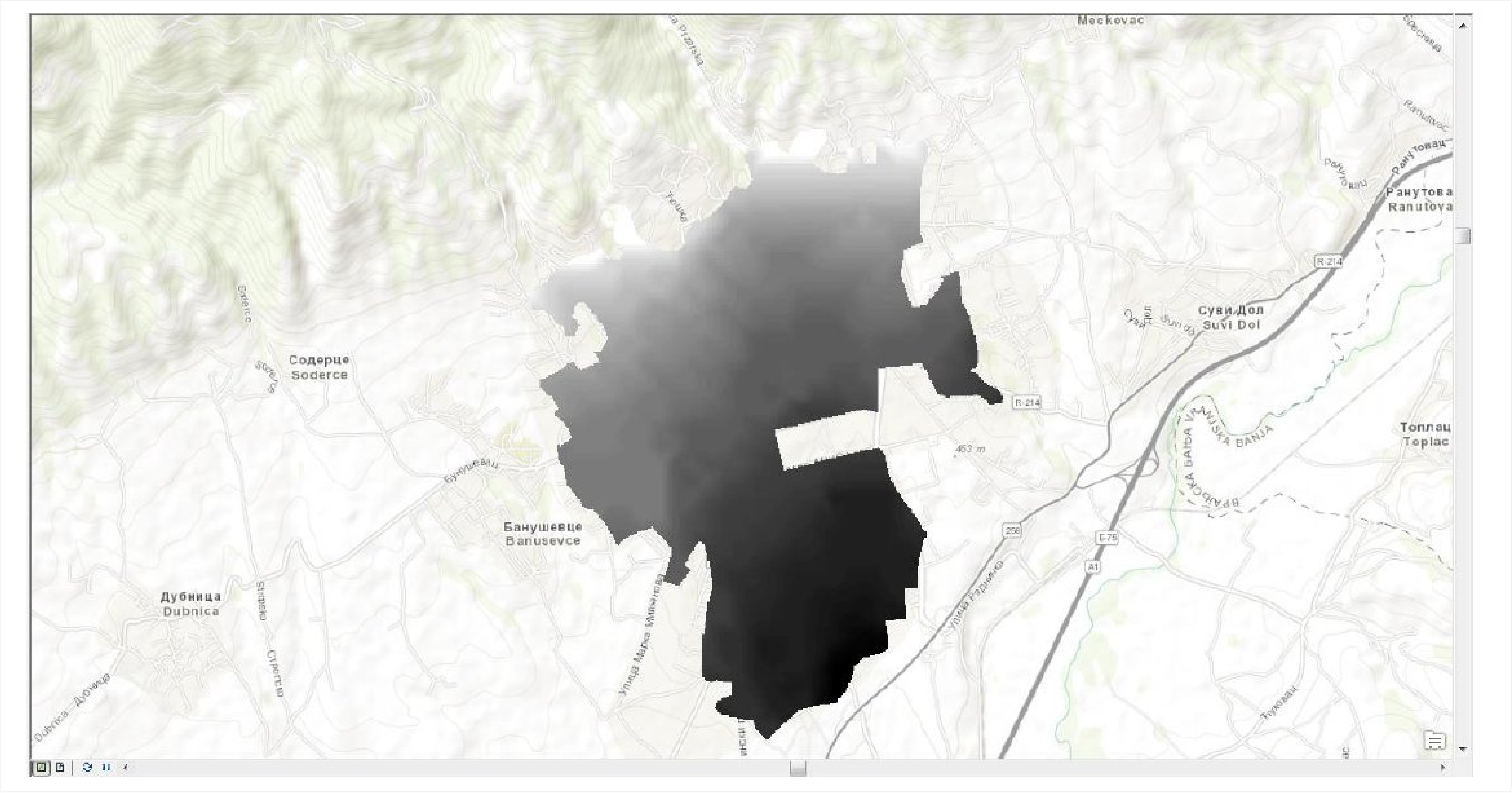


Figure 10 : The clipped DEM of the urban area of Vranje.

- Solar radiation parameters:
  - Zenith and Azimuth divisions - represents the number of sectors in the diffuse solar radiation map (sky map) from which diffuse radiation can originate. In this case, the accepted default value is 8.
  - Diffuse model type - there is a choice between two models: UNIFORM_SKY and STANDARD_OVERCAST_SKY. In this particular calculation, the first model is chosen, which considers the diffuse radiation as uniform from all directions.
  - Diffuse proportion - represents the share of diffuse radiation in total (global) radiation. The typical value for mostly clear sky conditions - 0.3.
  - Transmittivity - The fraction of radiation that passes through the atmosphere (averaged over all wavelengths). Values range from 0 (no transmission) to 1 (all transmission). The default is 0.5 for a generally clear sky.

6. Results and Discussion

Previously shown calculation is repeated for each pixel of the input DEM. The output raster representing the global radiation energy or the total amount of incoming insolation (direct and diffuse) calculated for each location of the input DEM (urban area of the city of Vranje).

The result of the SAT calculation is originally represented in units of watt-hours per square meter (Wh/m^2), but considering the aim of this paper, the output values in this work are displayed in kWh/m^2.

Figure 11 shows the amount of solar radiation energy/insolation during the year for the subject area. As it can be seen, the maximum amount of solar energy in certain parts of the area reaches a value of 1,373 kWh / m^2 annually. Dividing that value by 365 days the quotient of the average daily solar radiation energy for the area with the highest value of solar radiation energy is calculated, and the resulted daily solar radiation energy is 3.76 kWh/m^2.

Figure 12 shows the histogram with the insolation values for the studied area. In addition to this histogram, ASR tool also provides the basic statistics, according to which it is possible to get the mean value of the insolation for the studied area, which is 1,227 kWh / m^2.

Due to seasonal trends, solar radiation varies throughout the year. The Sun is higher in the sky in summer months than in winter months at the equivalent time of the day. It results in higher solar energy absorption by solar panels during summer months. In the case of PV panels, the longer days of summer allow PV cells to generate more energy than in the wintertime.

For that reason, as already mentioned in a previous section, the ASR is also used for the calculation of monthly solar radiation in January (winter time) and July (summertime).

Figure 13 shows two maps of the subject area. The left one represents the amount of solar radiation energy/insolation during January, and the right one represents the amount of solar radiation energy/insolation during July. As it can be seen, the maximum amount of solar energy in January for certain parts of the area reaches a monthly value of 42 kWh/m^2, and in July it reaches a monthly value of 181 kWh/m^2.

Figure 14 shows the histograms with the insolation values for the analyzed months, with the basic statistics, according to which it is possible to get the mean value of the insolation for the studied area and period of time, which is near 29 kWh / m^2 in January and near 175 kWh / m^2 in July.

By dividing the mean value of the monthly insolation with the number of days in months, the average daily solar radiation energy is calculated. The average daily solar radiation energy is 0.94 kWh / m^2 for January and 5.65 kWh / m^2 for July.

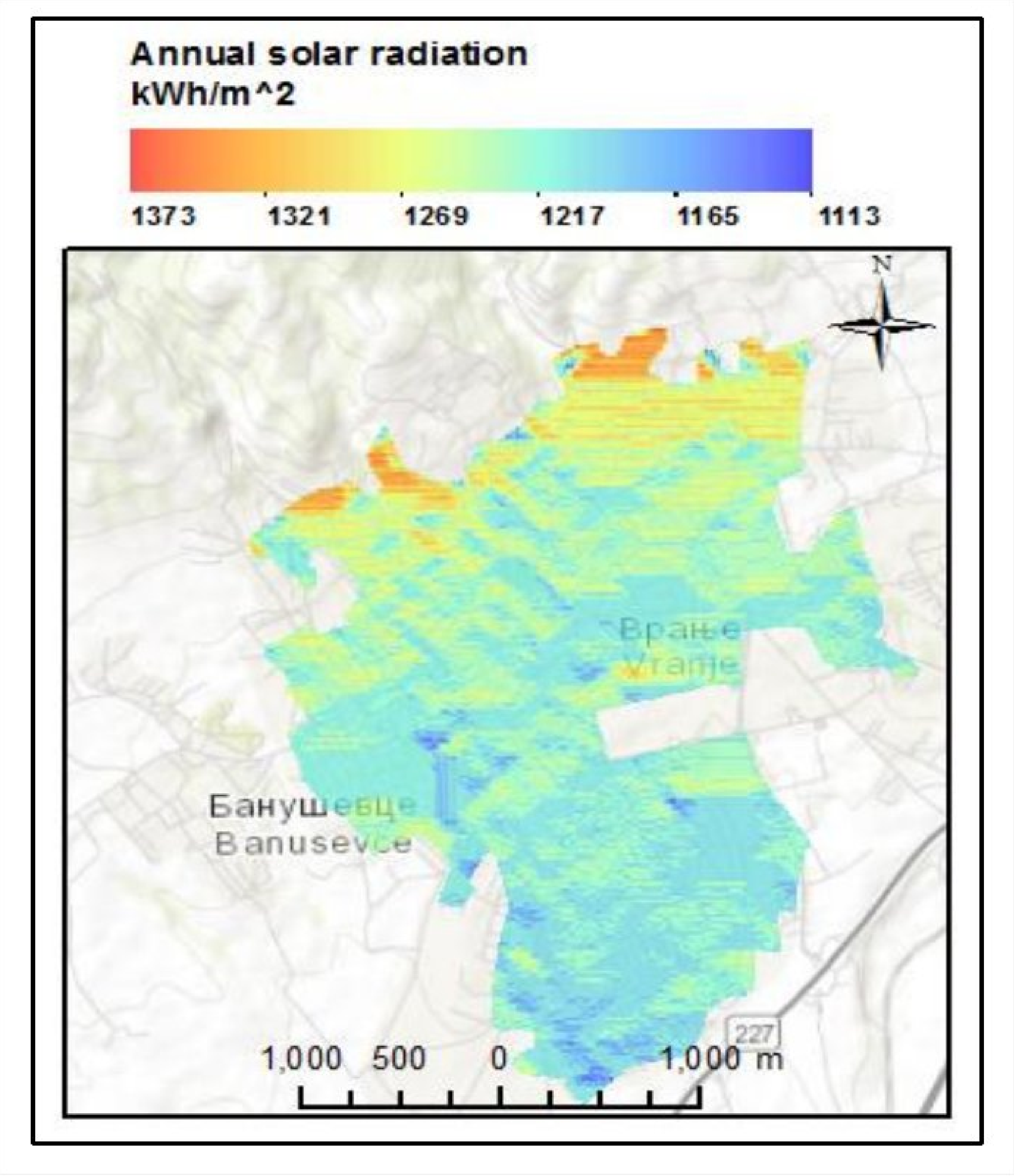
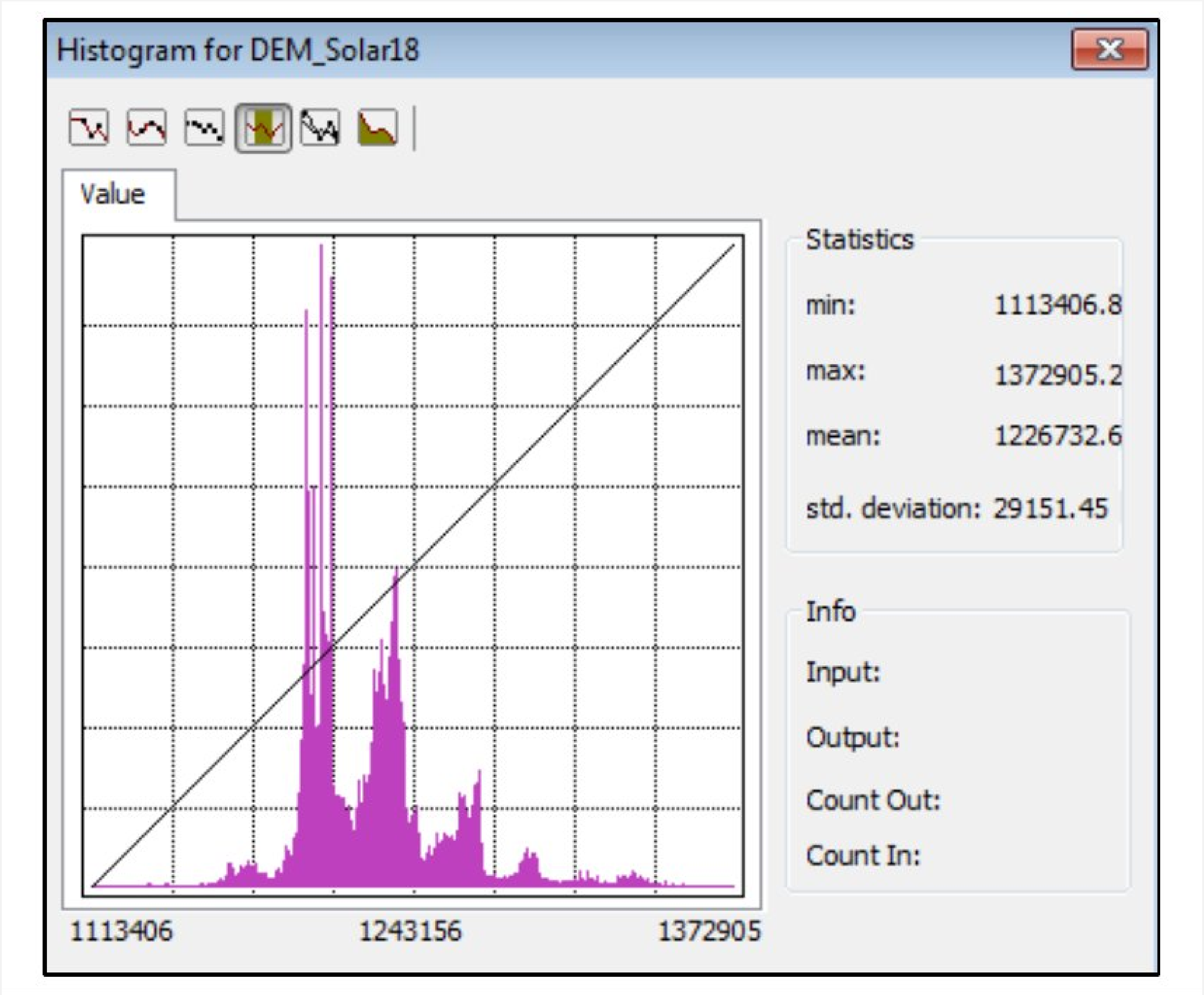


Figure 11: The annual map of the solar radiation energy/insolation.



Histogram for DEM_Solar18

Value

Statistics

min: 1113406.8

max: 1372905.2

mean: 1226732.6

std. deviation: 29151.45

Info

Input:

Output:

Count Out:

Count In:

Figure 12: Histogram of the annual solar radiation energy/insolation.

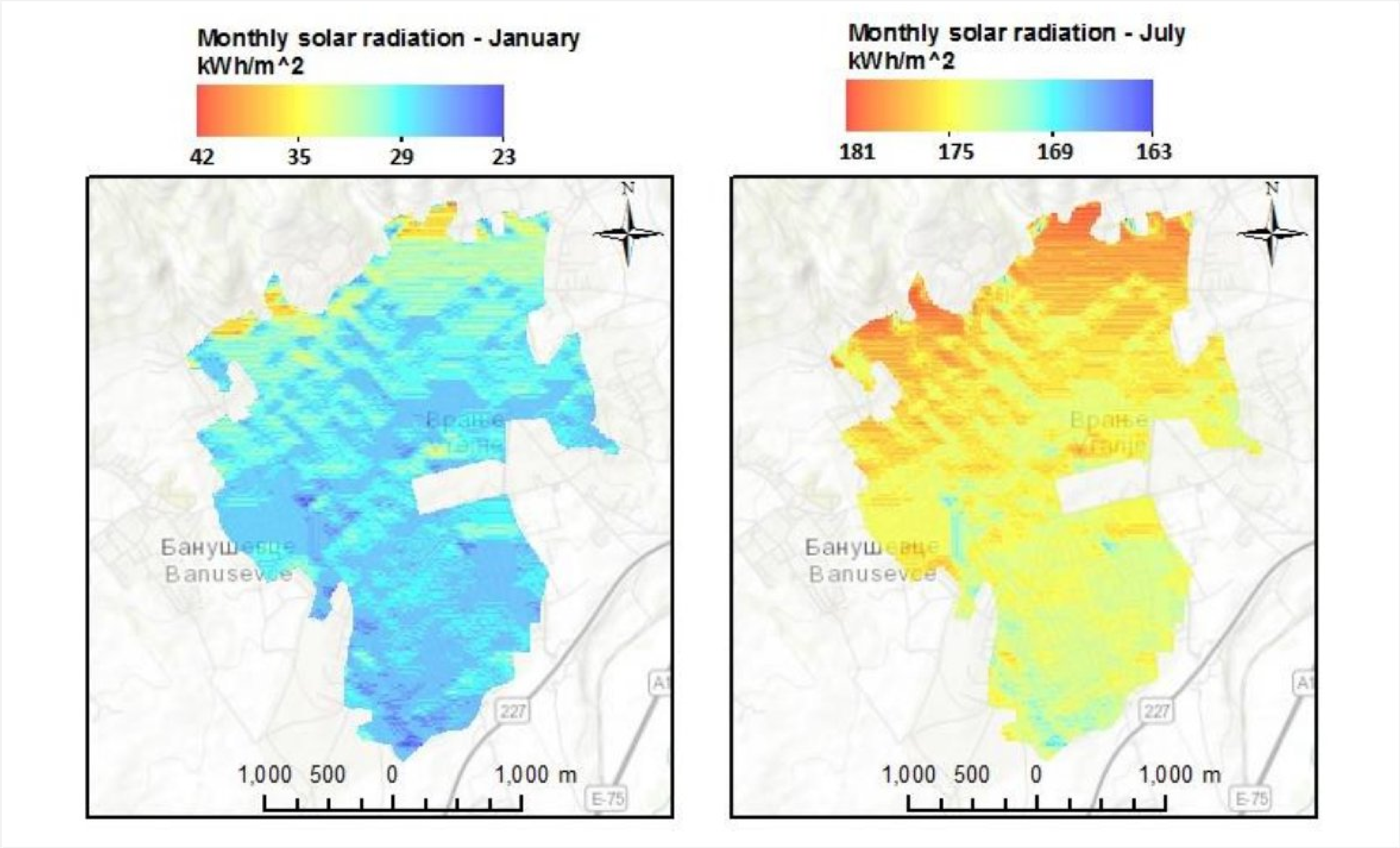


Figure 13: The monthly map of the solar radiation energy/insolation for January (left) and July (right).

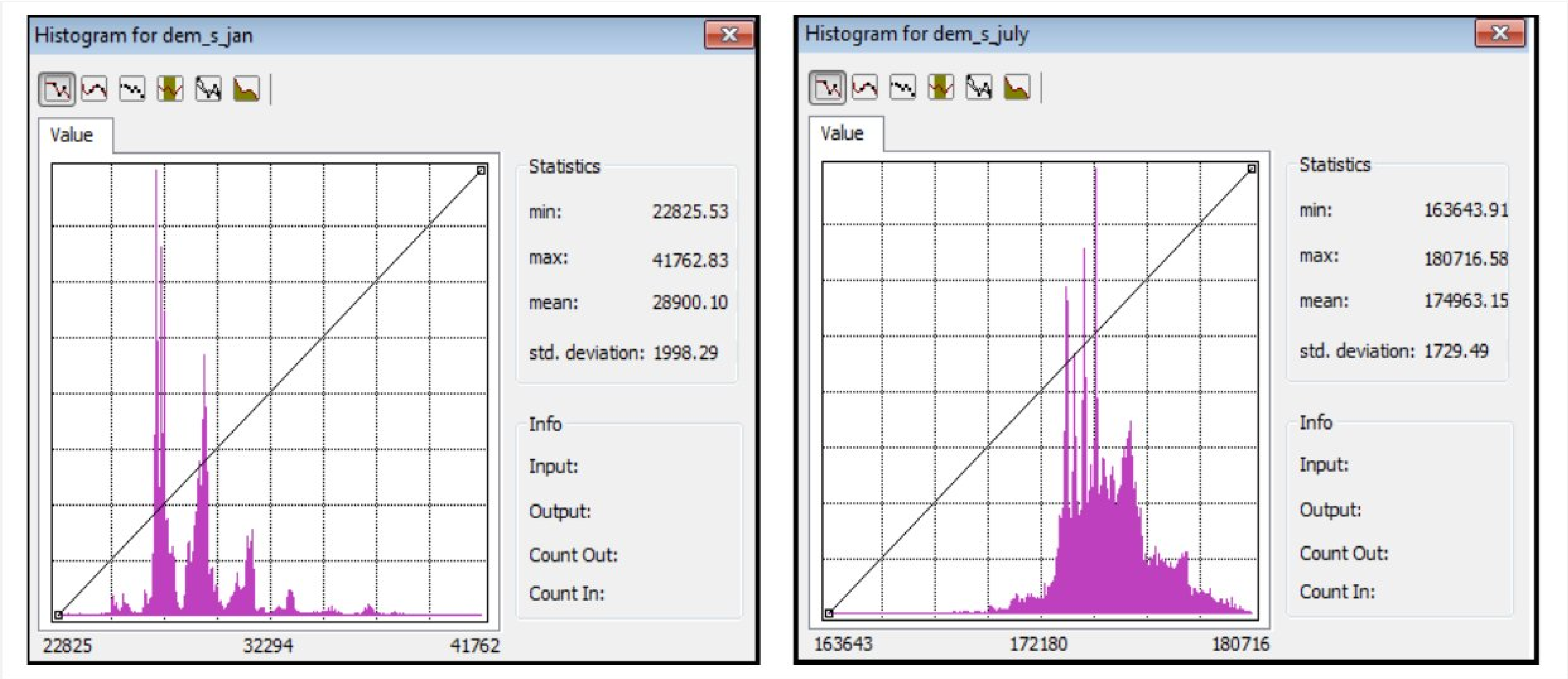
The obtained results of the solar radiation energy are one of the most important parameters for estimating electricity production from PV panels. In practice, the output of the PV electricity production is often estimated for the reason that the exact value of the output electricity depends on a large number of factors (type of PV cells, temperature of PV cells, effect of dust on PV cells, losses in the inverter, etc.). For the purpose of the estimation of the annual electricity production generated from a PV system, the equation retrieved from the website of United States Environmental Protection Agency (US EPA) is used:

$E = A * r * H * PR$ (11)

in which:

E = Energy (kWh);

A = Total solar panel Area (m^2);



Statistics
min: 22825.53
max: 41762.83
mean: 28900.10
std. deviation: 1998.29
Info
Input:
Output:
Count Out:
Count In:

Statistics
min: 163643.91
max: 180716.58
mean: 174963.15
std. deviation: 1729.49
Info
Input:
Output:
Count Out:
Count In:

Figure 14: Histogram of the monthly solar radiation energy/insolation for January (left) and July (right).

r = Solar panel efficiency (%);
H = Annual average solar radiation on tilted panels (shadings not included);
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9).

The factors for this equation were determined in consultation with experts at the National Renewable Energy Laboratory (NREL) based upon conservative best estimates and utilization of NREL's Annual Technology Baseline (ATB) tool and PVWatts Calculator (US EPA, 2019). Based on these resources, NREL recommends these factors (US EPA, 2019):

r = 15% solar panel efficiency of PV module, and
PR = 86% performance ratio.

Accepting the recommended values for “r” and “PR”, and assuming that the solar panel area is 1 m^2, the energy output from PV cells is:

$E = 1 * 15\% * 1373\ kWh/m^2 * 86\% = 177.12\ kWh$ (12)

As it can be seen from the proposed calculation above, the estimated annual electricity output would be 177.12 kWh for the installed panel area of 1 m^2.

7. Conclusions

Nowadays, there are many advanced software tools for the calculation of solar energy potential. In this work, it is proposed a methodology that combines ArcGIS software tool Area Solar Radiation (ASR) and the CORINE Land Cover (CLC) inventory for the identification of urban areas.

The advantage of this methodology is that it can give a quick estimation of solar energy potential for a specific space which there is no data about.

The results obtained from the ASR tool can be compared with the cited data in this work, which is based on the available literature. According to the ASR calculation, the maximum energy that can be annually expected on a certain location in the urban area of Vranje is 1,373 kWh / m^2, and according to aforementioned literature source (8), the estimated energy of solar radiation is around 1,550 kWh/m^2 for the southeast part of Serbia.

Also, comparing the results for the average daily solar energy in July to the map given in the introduction (15), it is noticeable that results obtained with the ASR (5.65 kWh / m^2 / day) for the analyzed space, are lower than the average daily solar energy for the south of Serbia (6.9 kWh / m^2 / day), based on the cited study in the introduction section.

In the end, it can be concluded that the proposed methodology for the determination of the solar radiation can be a good basis or a starting point for further technical and economic evaluations of the cost-effectiveness of using solar panels to generate electricity or for heating.

In this respect, the practical application of this methodology may be found in the initial part of one comprehensive feasibility study. A more detailed analysis would certainly include direct measurements of solar irradiation/insolation in the area, cost estimation, return on investment, analysis of land use and other factors affecting the use of renewable energy sources, i.e. solar radiation energy.

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