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# Calculating and comparing solar radiation results using GIS in the City Sarajevo area

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***Abstract*—Citizens of the city of Sarajevo and of other industrial cities are faced with a record number of days of increased pollution. In the winter months, the city of Sarajevo faces a large number of days of pollution caused mainly by the use of fossil fuels in individual houses for heating purposes. The current situation can be changed by the massive use of energy from renewable sources such as solar energy. This paper aims to evaluate the potential of solar energy in the city of Sarajevo. The use of Geographic Information Systems (GIS) represents the most significant technological and conceptual approach to spatial data analysis. Using existing models for calculating incoming solar radiation integrated in the GRASS GIS and SAGA GIS software, we achieved the goal and calculated the results for solar energy potential in the city of Sarajevo and presented them for the specific settlements. The model was implemented on the basis of created Digital Elevation Model (DEM) from Google Earth – free datasets, using techniques to collect and convert data with different software. Comparative results of selected model research are evaluated using the collected solar irradiance values from the meteorological stations, other research results, and the solar energy potential estimated via the Photovoltaic GIS Information System (PVGIS).**

**Keywords: QGIS, DEM, PVGIS, GRASS, SAGA, Solar energy potential**

## I. Introduction

THE COUNTRIES of the European Union are signatories to the Kyoto Protocol of 1997, which deals with the reduction of global warming of the planet by reducing the emission of greenhouse gases. GHG emissions decreased in the majority of sectors between 1990 and 2018, and particularly in energy supply, industry and the residential sector [1]. The European Union provides great support for electricity generation from renewable energy sources and gradually reduces the capacity consumption of fossil fuels. Solar energy is one form of renewable energy addressed by this research. The European Union significantly encourages the population to use this energy source to generate electricity.

Pollution in the city of Sarajevo is mainly caused by burning fossil fuels to heat individual housing units in settlements where individual housing prevails, and relatively more expensive prices for gas and electricity for heating. In most urban zones of collective housing (buildings) thermal energy is used for heating, consuming gas as a basic energy source, which is an environmentally friendly source of energy for combustion.

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Insolation is considered the direct solar radiation that reaches the earth's surface. The duration of insolation correlates with the latitude of the measurement location, elevation, land relief, and cloud cover. The terrain (relief) is the main factor that changes the distribution of solar radiation regionally and locally. Variability in terrain altitude, the slope of the terrain, aspect terrain, as well as the effect of shading, give special strong local gradients. Accurate and spatially distributed solar irradiance data are desirable for various applications (environmental science, climatology, ecology, photovoltaic installations, land management, etc.).

The growing availability of geospatial data and the demand for better analytic insight have helped to move location analysis from departmental (GIS) experts to other users [2], i.e. organizations for decision-making or users who want to take decisions about photovoltaic installations.

This study is based on the calculation of the solar potential using GIS methods and using free resources such as datasets from Google Earth and free software Quantum GIS - QGIS calculation [3], Geographic Resources Analysis Support System – GRASS [4], System for Automated Geoscientific Analyses - SAGA [5]. The aim of this study is to use certain GIS methods to obtain the results of solar potential in the city of Sarajevo. Validation and comparison of the results with previous ones and those obtained from Photovoltaic GIS Information System PVGIS [6] could provide information about the accuracy of GIS methods for solar potential calculation.

The study work of the region Abruzzo in Italy provides a framework for analyzing the sustainability of renewable energy sources using GIS. They present a GIS-based methodology to support decision-making in energy supply from renewable energy sources. One of the primary data required for the study was Digital Elevation Model - DEM [7]. The r.sun [8] model is a complex and flexible solar radiation model, fully integrated within the open-source environment of GRASS GIS [9]. The implemented equations follow the latest European research in solar radiation modeling. Integration in GRASS GIS enables to use interpolation tools that are necessary for data preparation [8]. The assessment of photovoltaic potential in the urban area of Bardejov in Slovakia was performed by using r.sun and a 3D city model. It was emphasized that the city has the potential to generate about 45% of its current electricity consumption by installing PV systems, although the study area included only two-thirds of the entire city. This confirms that solar potential estimates performed by the r.sun model can be used to assess solar potential as well as in urban areas [10]. In the research and estimation of the solar potential of roof surfaces in Baton Rouge (USA) on the basis of LiDAR data, information about the buildings (slope and aspect of roofs) and information concerning the roof surfaces using GRASS GIS software results indicate the annual solar potential of approx.1598,7 ($kWh/m^2$) [11]. Gorički M. with the group uses DSM to calculate the solar potential in the small town of Sveti Križ Začretje in northwestern Croatia. The data for the study were provided by an unmanned aerial vehicle. To evaluate the solar potential, they used the SAGA GIS software annually with a solar potential of 1900 ($kWh/m^2$) on the southern parts of the house roofs [12].

Validation of the obtained results could be done on the basis of solar radiation measurements, which are measured daily by hydrometeorological stations. In Sarajevo there are stations that measure insolation but not solar irradiance.

In Europe, there are several hundred weather stations that directly or indirectly measure solar radiation [8].

In this paper, we will present the methodology for estimating solar potential using available GIS tools and compare the obtained results using the city of Sarajevo as an example. In the following, we will first introduce the selected area and the method of data collection, then model the data, choose the appropriate method for the budget, and use it with free GIS tools. At the end, we will discuss the obtained results.

### A. *Data analysis and preparation area*

The city of Sarajevo was selected for the area of analysis due to the frequent pollution of the city and its population during the calendar year and the potential opportunity to make better decisions towards electricity generation from renewable energy sources, especially solar energy.

The area of the City of Sarajevo is located in the Mountain Valley macro-region in the Sarajevo-Zenica Valley, which is the southern end of the larger morpho structure. The lowest parts of the city area are located at an altitude of about 500 meters (zone of Rajlovac and Reljevo), while some of the settlement slopes in Stari Grad reach over 800 meters. The city center is located at an altitude between 540 and 550 meters. Mount Trebević (1627 meters) is a dominant mountain elevation near the city center. The Sarajevo Valley, where most of the city of Sarajevo is located, is in the east-west direction in a length of about 12 (km) and 1-1.5 (km) wide, with geographical coordinates 43.8563°N, 18.4131°E. The area of analysis is shown in Fig. 1.

Free software QGIS version was used to prepare and process data. Due to the widespread data availability and the possibility to repeat the results and the possibility to use free data for processing, the Google Earth application is used to download data from which DEM is created.

The area bounded by a red rectangle with dimensions (11.5 km long and 7.5 km wide) is an area for analysis. This is a very wide area for the creation of DEMs and an area of about 82 $km^2$. For this survey, we are collecting data for the following 6 settlements:

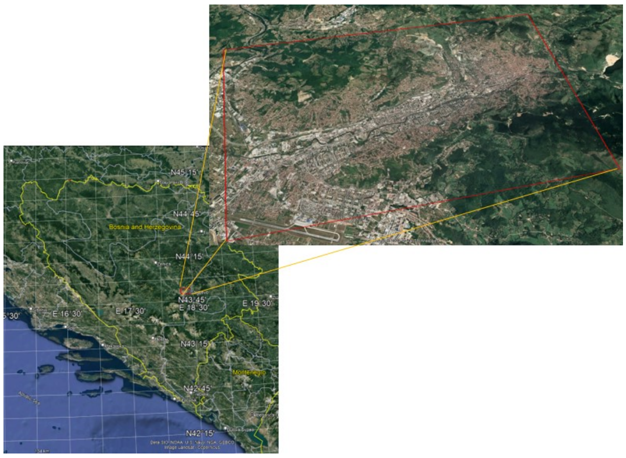

Fig. 1. A view of wider surroundings of the city of Sarajevo

1. Nedžarići, residential houses, lowland part of the city,
2. Grbavica, blocks of flats, lowland plant of the city,
3. Buća Potok, residential houses, hillside area, south –orientation,
4. Širokača-Krka, residential houses, hillside area, north orientation,
5. Šip, blocks of flats and meadows, mountainous area, south-west orientation,
6. Sedrenik-Grdonj, residential houses, south-west orientation.

### B. *Insolation and insolation data for Sarajevo*

Insolation is the time for which the earth's surface receives direct solar radiation. The duration of solar radiation correlates with the latitude of the measurement location, altitude, land relief, and cloud cover. A heliograph is a measuring device consisting of a glass ball 9-12 (cm) in diameter recording the sun rays and focus them onto a strip of paper that burns under the influence of heat. Since older versions of heliographs did not indicate values below 120 ($W/m^2$), this threshold was retained by the World Meteorological Organization Convention and in more modern measuring instruments "unpublished" [13].

The term cloud cover refers to the degree to which the sky is covered with clouds, i.e. the size of the cloud cover relative to the entire sky. Smaller values mean brighter days, so the value of 1 means coverage of up to 10% of the sky with clouds, cloudiness 10 means that the sky is completely covered with clouds. According to [14] the annual insolation from the Bjelave hydro-meteorological station for a period of 20 years amounts 1919 hours i.e. 5(h) per day. The monthly sum of insolation ($I$) is calculated according to (1):

$$I = i_1 + i_2 + \cdots + i_n \tag{1}$$

$i_1, i_2, \ldots, i_n$ - the daily sum of sunshine duration for the first, second and $i^{th}$ day of the month.

The annual insulation ($I_g$) is calculated according to (2):

$$I_g = I_1 + I_2 + \cdots + I_{11} + I_{12} \quad (2)$$

$I_1, I_2, I_3, \ldots, I_{12}$ - represent the insolation for the first, second, third,..., and twelfth month, respectively [14].

### C. Irradiation on a horizontal plane

The term irradiance is used to consider the solar power (instantaneous energy) falling on unit area per unit time ($W/m^2$). The term irradiation is used to consider the amount of solar energy falling on unit area over a stated time interval ($W/m^2$) [8]. According to [15] integrating the obtained value by time, the total energy of radiation the unit area in the observed interval is obtained. By integrating the intensity of solar radiation at different time intervals, we obtain hourly, daily, monthly, and annual irradiation ($H$):

$$H = \int_{t_1}^{t_2} G_{0n} cos\theta_z dt \quad (3)$$

$G_{0n}$ – extraterrestrial radiation intensity on a surface perpendicular to the radiation ($W/m^2$); $G_0$ – solar constant 1367 ($W/m^2$); $n$ – ordinal number of days in a year.

$$H_0 = \int_{-\omega_s}^{\omega_s} G_0(1 + 0,34cos\frac{n}{356}360) (sin\varphi sin\delta + cos\omega cos\delta cos\omega)d\omega \quad (4)$$

$$H_0 = \frac{24}{\pi} G_0(1 + 0,364cos\frac{n}{356}360) (\frac{\pi}{180}\omega_\mathbf{s} sin\varphi sin\delta + cos\varphi cos\delta sin\omega_\mathbf{s}) \quad (5)$$

$H_0$ – the irradiation on a horizontal plane; ($Wh/m^2$); $\omega_\mathbf{s}$ – angle of sunrise (°); $-\omega_\mathbf{s}$ – angle of sunset (°); $\delta$ – solar declination (°); $\varphi$ – latitude (43°52 for Sarajevo) (°).

The average annual extraterrestrial irradiation in the city of Sarajevo is obtained by calculating the average daily extraterrestrial irradiation for each day of the year. Table I shows the average monthly irradiation of a horizontal plate area 1 ($m^2$) at the latitude (43°52 for the city of Sarajevo). Calculated values of extraterrestrial irradiation do not take into account the influence of absorption, diffuse radiation and reflection of solar radiation, effects of clouds, pollution, height of the measuring plate, etc., which strongly influences the measurement results “unpublished” [13].

TABLE I
THE EXTRATERRESTRICAL IRRADIATION ON A PLANE ($kWh/m^2$) [13]

| January | February | March | April | May | June |
|---|---|---|---|---|---|
| 112 | 142 | 222 | 260 | 339 | 348 |
| **July** | **Augus** | **Sept** | **Octob** | **Novem** | **Decem** |
| 348 | 307 | 237 | 176 | 118 | 99 |

### D. Data modeling

The digital elevation model (DEM) is considered one of the most important input data for the purpose of terrain's (relief) surface representation. DEM system [16]. There is no harmonized terminology about the name in the literature. Digital terrain model (DTM), this concept, which includes relief as well as other general geographic objects, refers to the part of the terrain that has certain distinctive features.

The specificity of this paper is reflected in the generation of DEM from free data sources. The quality and quantity of data as well as the method of collecting these data are the most important for obtaining quality DEM. The access was done through the free online application Google Earth and the data offered in it on the Internet. Fig. 2 shows the sequence diagram of steps that were performed to achieve the final DEM product. Creating a vector file in the Google Earth web platform, i.e. when such a trajectory is drawn over the desired area with sufficient desired density, a file with a .kml extension is formed. The trajectory is clearly marked with latitude, longitude, and altitude. A larger number of points in the trajectory represents a more detailed DEM. After creating the trajectory, data extraction was started using certain free-type applications. To convert a .kml file into a .gpx file, the GPS Visualizer was used, where a certain conversion method saved .gpx files. The next step was to create a .scv file where you can visually see the numerous values of each point from the trajectory with latitude, longitude and altitude and this process was done using TCX Converter - free software. By processing .csv file and inputting it into QGIS [3], we created a set of points from which we obtained DEM shown in Fig. 3 by post-processing and applied algorithm.

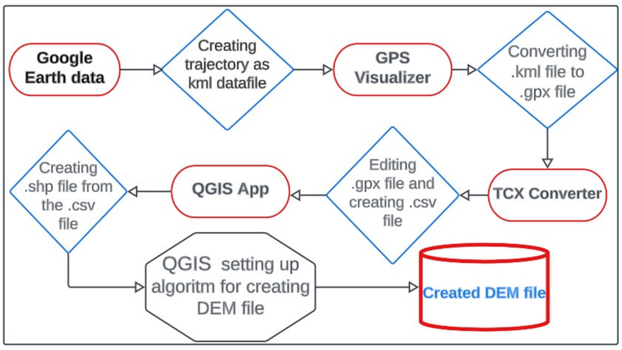


Fig. 2. The sequence diagram of steps for creation of DEM

## II. OVERVIEW OF GIS METHODS FOR ESTIMATING SOLAR POTENTIAL

To calculate the potential of solar radiation with GIS methods, certain raster data such as DEM or DTM terrain models are needed. Several methods have been developed and are used in different GIS tools. Each of these methods has its own specific parameters.

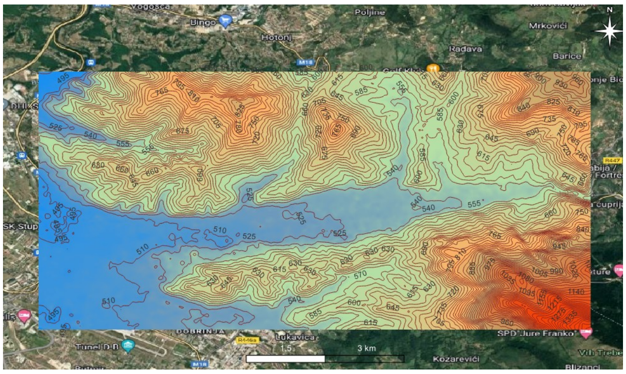

Fig. 3. Created DEM – City of Sarajevo

The free software GRASS GIS [4] and SAGA GIS [5] were used for calculations and analyses, and the data used were also obtained on a free basis or created by the authors.

The algorithm for the Satellite-Based Retrieval of Solar Surface Irradiance in Spectral Bands [17] has been implemented in PVGIS and is based on solar irradiance results. PVGIS [6] is often used as a basis for informative display of monthly and daily solar potential.

Hofierka and Šuri created an open-source solar radiation model called r.sun [8], GRASS GIS [4] is the best known open source software based on a methodology that uses equations published in the European Solar Radiation Atlas (ESRA) [18] and applies the r.sun model to calculate the solar potential. According to [5] SAGA is a specialized digital terrain analysis tool on a comprehensive and widely used GIS platform for scientific analysis and modeling. It is designed for easy and efficient implementation of spatial algorithms and thus serves as a framework for the development and implementation of geoscientific methods and models. Today, SAGA is a modular programmable GIS software that provides raster analyses of DEM and DSM substrates to estimate solar potential, with the ability to input specific data such as solar constant, atmospheric pressure, atmospheric height, humidity, etc. Solar radiation models integrated into GIS systems provide rapid, cost-effective, and accurate estimates of radiation over large areas, considering surface slope, aspect, and shading effects. Significant progress has been made in the development of solar radiation models over the past two decades [8].

## III. SOLAR ENERGY POTENTIAL CALCULATION

### A. Solar radiation and photovoltaic data

PVGIS [6] is an information system that allows the user to get data on solar radiation and photovoltaic system energy production, at any place in most parts of the world. It is completely free to use, with no restrictions on what the results can be used for, and with no registration necessary. PVGIS can be used to make several different calculations. As an example of solar potential in the city of Sarajevo, we used the PVGIS SARAH2 database, which uses predefined samples of satellite image resolution ($5km$ x $5km$) for the period from 2005 to 2020 [6]. PVGIS provides monthly solar potential values, from which we calculated the mean annual potential. Table II. shows the solar radiation for each settlement and refers to the radiation at an abduction angle with a calculated optimal plate angle. Table III. represents the solar radiation on a horizontal panel, i.e.the panel at an angle of $0^o$.

TABLE II
IRRADIATION ON OPTIMALLY INCLINED PLANE ($kWh/m^2$)

| **Sett:** | **Nedžari** | **Grbavi** | **Buca Pot** | **Širok** | **Šip** | **Sedre** |
|---|---|---|---|---|---|---|
| **Lat:** | 43.837 | 43.851 | 43.864 | 43.850 | 43.884 | 43.876 |
| **Lon:** | 18.337 | 18.395 | 18.36 | 18.431 | 18.402 | 18.429 |
| **Ang:** | $37^o$ | $37^o$ | $34^o$ | $31^o$ | $35^o$ | $35^o$ |
| **Jan** | 98,21 | 96,54 | 101,9 | 49,7 | 100,9 | 102,21 |
| **Apr** | 185,3 | 186,04 | 190,9 | 183,1 | 189,4 | 189,33 |
| **July** | 180,5 | 185,13 | 182,4 | 188,1 | 184 | 183,53 |
| **Oct** | 122,6 | 122,42 | 125,7 | 102,5 | 124,4 | 125,16 |
| **Dec** | 55,7 | 57,56 | 58,2 | 28,2 | 60,93 | 62,96 |
| **Sum** | 1572 | 1582,3 | 1593,4 | 1412 | 1579 | 1584,8 |

TABLE III
SOLAR IRRADIATION ON HORIZONTAL PLANE ($kWh/m^2$)

| Sett | Nedžar | Grbavi | Bu´ca Pot | Široka | Šip | Sedren |
|---|---|---|---|---|---|---|
| Jan | 54,43 | 54,11 | 54,99 | 37,03 | 55,4 | 55,57 |
| Apr | 164,2 | 164,7 | 168,9 | 161,78 | 167 | 167,6 |
| July | 185,88 | 189,6 | 188,99 | 189,11 | 188,1 | 188,1 |
| Oct | 86,79 | 86,47 | 87,59 | 77,55 | 87,26 | 87,37 |
| Dec | 35,12 | 35,71 | 35,69 | 25,37 | 36,93 | 37,33 |
| Sum | 1349 | 1355 | 1360,1 | 1274,25 | 1348 | 1347 |

### B. Geographic Resources Analysis Support System

The installed GRASS GIS [4] software with version 7.6.1 was used to analyze the terrain of the observed area and then calculate the solar radiation. In the first case, a database was created with the basic element of DEM resolution ($30m$ x $30m$), shown in Fig. 3. The DEM was used to create slope and aspect, shown in Fig. 4. These two graphical representations are very important for us to calculate the solar potential in the selected area with the setting of certain parameters (Linke coefficient of atmospheric turbidity and albedo). GRASS does not count the annual solar radiation for the whole year but for each day separately. Fig. 5 illustrates solar irradiance for 01 July and the locations from which it was collected for records and analysis. Given the width of the workspace shown in Fig. 5 on the left and the resolution of ($30m$ x $30m$) and the diameter of a point from Fig. 5 from which the data was collected, which is about 200 ($m$), it is understandable that when collecting the solar potential from one of these points and repeated procedures, there is a possibility that we will not hit the previous pixel, but neighboring ones. Thus, there is a possibility that the value of the potential will also be different, but not drastically. The solar radiation map for the middle day of December is shown in Fig. 5 on the right.

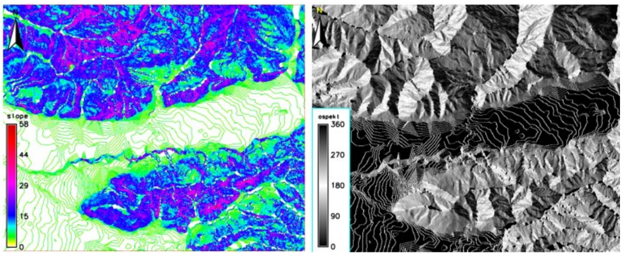

Fig. 4. Graphical presentation of slope on the left side and aspect on the right side

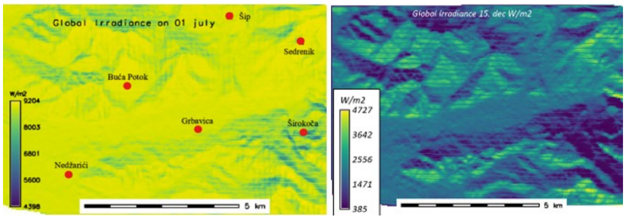


Fig. 5. Locations for collecting data for Solar irradiation for the 01. July on the left, and Solar irradiation data for 15. December on the right

The mean value of solar potential for each month for a given location is determined from the daily values, which are shown in Table IV.

TABLE IV
AVERAGE SOLAR IRRADIATION ON THE MONTHLY BASIS IN DIFFERENT SETTLEMENTS ($kWh/m^2$) [4]

| Sett: | Nedzar | Grbav | Buca Pot | Sirok | Sip | Sedren |
|---|---|---|---|---|---|---|
| **Jan** | 67 | 67 | 110 | 14 | 74 | 97 |
| **Apr** | 188 | 185 | 213 | 69 | 194 | 208 |
| **July** | 242 | 241 | 246 | 186 | 244 | 247 |
| **Nov** | 72 | 69 | 109 | 15 | 80 | 102 |
| **SUM:** | 1798 | 1776 | 2113 | 944 | 1879 | 2045 |

Very interesting are the areas of the city located on the slopes of mountain Trebević, where the solar potential ranges from about 0.4 ($kWh/m^2$) in winter to 7 ($kWh/m^2$) in summer. The results obtained with this method range from about 950 ($kWh/m^2$) in areas of the city facing north and northwest, located on the sides and foothills of the mountain Trebević, to 1800 ($kWh/m^2$) in areas located in the lowland part of the city, to 2100 ($kWh/m^2$) on the slopes of the city facing south, southeast and southwest.

### *C. System for Automated Geoscientific Analyses*

SAGA GIS [5] was used to calculate the solar potential in a wide area of the city of Sarajevo. Unlike GRASS, it can calculate solar potential for the whole year. The algorithm for calculating the solar potential also uses as a basis the created DEM of areas, based on which the Sky view factor is calculated, and accordingly the algorithm calculates the solar radiation with the adjustment of certain parameters. For this calculation, we used a created example of DEM resolution

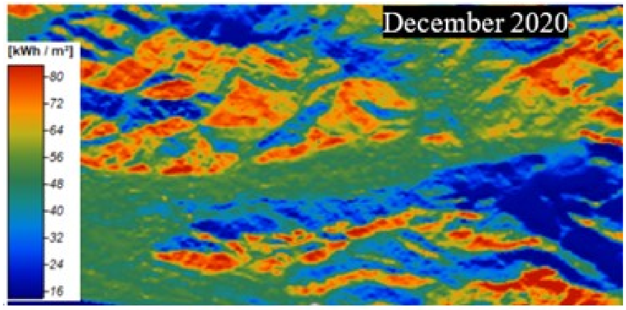


Fig. 6. Solar radiation map for December

($30m$ x $30m$). To display the average value of solar potential on monthly basis in Fig. 6, we set the algorithm sampling for each day of the month and each half hour during the day, which is a rather detailed calculation.

The SAGA GIS results for 2020 range from 1449 to 2099 ($kWh/m^2$). A more detailed overview of the selected sites/locations is shown in Table V.

TABLE V
SOLAR POTENTIAL RESULTS IN SPECIFIC SETTLEMENTS ($kWh/m^2$)

| Sett: | Nedzar | Grbavic | Buca Pot | Sirok | Sip | Sedre |
|---|---|---|---|---|---|---|
| **Jan.** | 59 | 54 | 66 | 33 | 67 | 93 |
| **Apil** | 191 | 187 | 199 | 173 | 198 | 216 |
| **Aug.** | 211 | 208 | 218 | 182 | 218 | 230 |
| **Dec.** | 49 | 55 | 44 | 15 | 58 | 82 |
| **SUM:** | 1777 | 1729 | 1875 | 1449 | 1861 | 2099 |

It is expected that the result of solar potential in the settlement of Sedrenik is greater than the potential in the lowland parts of the city due to the higher location and orientation of the settlement to the south and southwest. The lowest solar potential is illustrated in the area of Širokača, which is located on the northern side of the Trebević Mountains, adding extra shade in the morning hours Fig. 6.

The dark shades on the map show fairly shaded areas and slopes facing north and northwest, where we get the lowest values of solar radiation.

## IV. DISCUSSION AND COMPARISON OF RESULTS

The estimated results of solar potential in Sarajevo Canton "unpublished" [13] amount ca. 2700 ($kWh/m^2$). The annual irradiation on a horizontal plane of 1 ($m^2$), based on insolation, was estimated in range of 1100 to 1550 ($kWh/m^2$) according to the study "unpublished" [19]. The annual solar potential PVGIS, GRASS and SAGA for the Sarajevo area is shown in Table VI. Using PVGIS does not require extensive foreknowledge and expertise to obtain results, which makes PVGIS very easy to use. To use GRASS and SAGA GIS, it is necessary to have good knowledge in managing GIS applications and a good knowledge of the factors that affect the amount of solar radiation. There is a noticeable difference in solar potential results, especially in methods (GRASS and SAGA) in which we used DEM ($30m$ x $30m$) compared to PVGIS results which uses satellite image resolution ($5km$ x $5km$) from its database, shown in Table VI.

TABLE VI
AVERAGE ANNUAL SOLAR POTENTIAL ($kWh/m^2$)

| Settlement | PVGIS | GRASS | SAGA |
|---|---|---|---|
| **Nedžarići** | 1349 | 1798 | 1777 |
| **Grbavica** | 1355 | 1776 | 1729 |
| **BućaPotok** | 1360 | 2113 | 1875 |
| **Širokača** | 1274 | 944 | 1449 |
| **Šip** | 1348 | 1879 | 1861 |
| **Sedrenik** | 1347 | 2045 | 2099 |

The differences are especially noticeable in parts of the city that are in the shadow of mountain Trebević in winter months. Colleagues from Croatia, who used SAGA in research [12] concluded that the solar potential results appear to be quite large and that the actual energy of solar energy that can be obtained annually from solar radiation is much lower. Although Sveti Križ Začretje (Croatia) is 200 ($km$) farther north than Sarajevo, SAGA provided them results for solar potential of about 1900 ($kWh/m^2$).

## V. CONCLUSION

The aim of this study was to obtain solar potential results in the city of Sarajevo using certain GIS methods. We found that GIS methods provide the user with detailed insight into solar potential with the availability of certain datasets and the level of GIS management expertise required to perform such an analysis. Based on the size of the satellite image resolution sample that makes up the PVGIS database, it can be concluded that PVGIS is more commonly used for large-area solar potential calculations, such as states. Since GRASS and SAGA do not have predefined datasets, they can use detailed DEM for input data. Due to the level of detail of the DEM created ($30m$ x $30m$), we have a more pronounced relief of the area we analyzed, so the shading effects are more visible, especially in winter months, which was reflected in the calculation of solar potential at these locations. Thus, we conclude that GRASS and SAGA are better suited for calculations of smaller areas. Based on the results, we get the impression that in micro-sites, the detail of DEM significantly increased the difference of solar potential in certain areas compared to the results of PVGIS. Looking at the solar potential results through the details of DEM samples, we can conclude that GRASS and SAGA provide more accurate results, which has been confirmed by some previous works. The results of GRASS and SAGA differ very little with maximum deviations up to 0.96%, except for the results for settlements at the foothill of mountain Trebević. Unfortunately, the validation of the results cannot be established due to the lack of measuring stations that record solar radiation (the nearest registered stations are located in Budapest and the Austrian Alps). A possible improvement in terms of more accurate solar potential results could be achieved by creating a digital surface model LIDAR record or satellite image resolution (1m x 1m).

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