Analysing Solar Radiation in Suceava

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Abstract

In this research paper was analysed the solar radiation in a bounded area of Suceava city using Solar Radiation module in ArcGis. Feature classes: buildings, streets and contours were organized in a geospatial database. TIN was generated by using contours feature class in order to obtain solar radiation rasters. We can extrude buidings for a better 3D visualization. For solar radiation analysis, Solar Radiation Tools were used: Area Solar Radiation, Points Solar Radiation and Solar Radiation Graphics. Points solar radiation analysis is used to calculate the amount of radiant energy for a given location. Solar radiation calculations can be performed for specified locations only by using a landcape raster and buildings shapefile. The amount of solar radiation during one year (T_0) was calculated. Area Solar analysis is used to compute the insolation across an entire landscape. Different time configurations for analysing solar radiation were used: multi-day time configurations with the maximum range of days a total of one year (2014), special days time configurations and within-day time configurations with the maximum range of time set by one day (24 hours). Solar radiation graphics provides informations on the visibility or obstructions of the sky; related solar map sectors shows changes in elevation/ azimuth; Sun position and skymap provides information on the diffuse radiation areas.

Keywords

Solar radiation, viewshed, sunmap, skymap

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1. Introduction

Incoming solar radiation (insolation) is the primary driver for our planet's physical and biological processes. At a landscape scale, topography is the major factor modifying the distribution of insolation.

Variability in elevation, surface orientation (slope and aspect), and shadows cast by topographic features create strong local gradients of insolation. This leads to high spatial and temporal heterogeneity in local energy and water balance, which determines microenvironmental factors such as air and soil temperature regimes, evapotranspiration, snow melt patterns, soil moisture, and light available for photosynthesis.

These factors in turn affect the spatial patterning of natural processes and human endeavor. Accurate insolation maps at landscape scales are desired for many applications. Although there are thousands of solar radiation monitoring locations throughout the world (many associated with weather stations), for most geographical areas accurate insolation data are not available.

Simple interpolation and extrapolation of point–specific measurements to areas are generally not meaningful because most locations are affected by strong local variation. Accurate maps of insolation would require a dense collection station network, which is not feasible because of high cost. Spatial solar radiation models provide a costefficient means for understanding the spatial and temporal variation of insolation over landscape scales. [1]

Spatial solar radiation models provide a costefficient means for understanding the spatial and temporal variation of insolation over landscape scales. [2]

Such models are best made available within a geographic information system (GIS) platform, whereby insolation maps can be conveniently generated and related to other digital map layers.

Spatial insolation models can be categorized into two types: point specific and area based. Point-specific models compute insolation for a location based upon the geometry of surface orientation and visible sky. In contrast, area-based models compute insolation for a geographical area, calculating surface orientation and shadow effects from a Digital Elevation Model (DEM). [3]

In this research paper we use solar analyst instruments for analysing solar radiation components in a geographical area of Suceava. Specific position and time causes differences of insolation over a landscape scale.

2. Theory and design of the Solar Analyst

a. Hemispherical Viewshed Algoritm

The solar radiation analysis tools in the ArcGIS Spatial Analyst extension enable us to map and analyze the effects of the sun over a geographic area for specific time periods using hemispherical viewshed algoritm developed by Fu and Rich. [4]
Global radiation ($Global_{tot}$) is calculated as the sum of direct (Dirtot) and diffuse (Diftot) radiation of all sunmap and skymap sectors, respectively [5]:

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

Total direct insolation (Dirtot) for a given location is the sum of the direct insolation (Dirθ,α) from all sunmap sectors:

$$Dir_{tot} = \sum Dir_{\Theta,\alpha} \quad (2)$$

The direct insolation from the sunmap sector (Dirθ,α) with a centroid at zenith angle (θ) and azimuth angle (α) is calculated using the following equation:

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

where:

- S_{Const} is 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.
- β is transmisivity of the atmosphere (averaged over all wavelengths) for the shortest path (in the direction of the zenith);
- m(θ) is the relative optical path length, measured as a proportion relative to the zenith path length
- $Sun_{Dur\theta,\alpha}$ is 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). For partial sectors (near the horizon), the duration is calculated using spherical geometry;
- $SunGap_{\theta,\alpha}$ is the gap fraction for the sunmap sector;
- $AngIn_{\theta,\alpha}$ is the angle of incidence between the centroid of the sky sector and the axis normal to the surface.

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:

$$Difn_{\Theta,\alpha} = R_{glb} * P_{dif} * Dur * SkyGap_{\Theta,\alpha} * Weight_{\Theta,\alpha} * \cos(AngIn_{\Theta,\alpha}) \quad (4)$$

where:

- R_{glb} is the global normal radiation;
- P_{dif} is 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 is the time interval for analysis;
- $SkyGap_{\theta,\alpha}$ is the gap fraction (proportion of visible sky) for the sky sector; $Weight_{\theta,\alpha}$ is the proportion of diffuse radiation originating in a given sky sector relative to all sectors (see equation below);
- $AngIn_{\theta,\alpha}$ is the angle of incidence between the centroid of the sky sector and the intercepting surface.

The global normal radiation (Rglb) can be calculated by summing the direct radiation from every sector (including obstructed sectors) without correction for angle of incidence, then correcting for proportion of direct radiation, which equals to 1- P_{dif}:

$$R_{glb} = (S_{const} * \sum(\beta^{m(\Theta)})) / (1 - P_{dif}) \quad (5)$$

b. Theory: Use of Hemispherical Viewsheds in Solar Radiation Models

The solar radiation tools can perform calculations for point locations or for entire geographic areas. This involves four steps:
1. The calculation of an upward-looking hemispherical viewshed based on topography.
2. Overlay of the viewshed on a direct sunmap to estimate direct radiation.
3. Overlay of the viewshed on a diffuse skymap to estimate diffuse radiation.
4. Repeating the process for every location of interest to produce an insolation map.
The viewshed is a raster representation of the entire sky that is visible or obstructed when viewed from a particular location. [5]

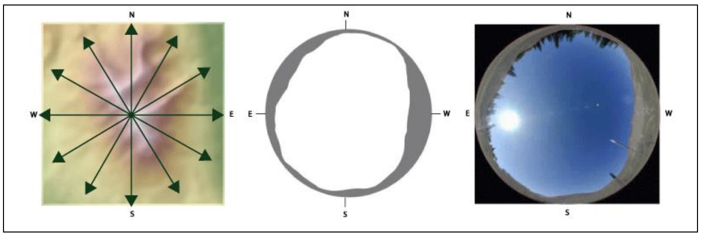

Fig. 1 Overlaping viewshed on a hemispherical photograph

The direct solar radiation originating from each sky direction is calculated using a sunmap in the same hemispherical projection as the viewshed. A sunmap is a raster representation that displays the sun track, or apparent position of the sun as it varies through the hours of day and through the days of the year. This is similar to you looking up and watching as the sun's position moves across the sky over a period of time.
The sunmap consists of discrete sunmap sectors defined by the sun's position at particular intervals during the day (hours) and time of year (days or months). The sun track is calculated based on the latitude of the study area and the time configuration that defines sunmap sectors. For each sunmap sector, a unique identification value is specified, along with its centroid zenith and azimuth angle. The solar radiation originating from each sector is calculated separately, and the viewshed is overlaid on the sunmap for calculation of direct radiation.

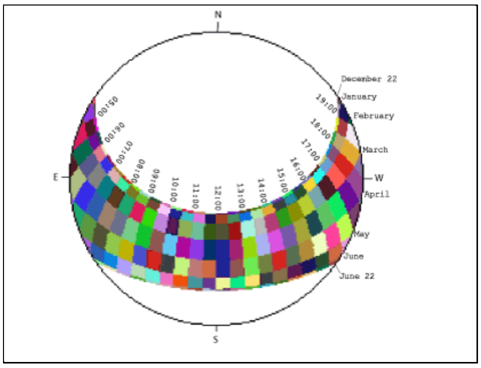

Fig. 2. Estimating direct solar radiation using sunmap

Diffuse radiation originates from all sky directions as a result of scattering by atmospheric components (clouds, particles, and so forth). To calculate diffuse radiation for a particular location, a skymap is created to represent a hemispherical view of the entire sky divided into a series of sky sectors defined by zenith and azimuth angles. Each sector is assigned a unique identifier value, along with the centroid zenith and azimuth angles. Diffuse radiation is calculated for each sky sector based on direction (zenith and azimuth). [6]

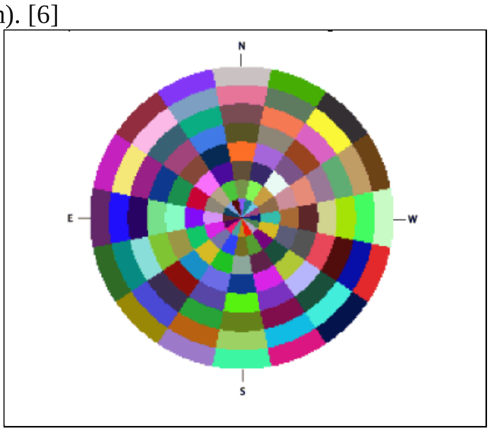

Fig. 3. Estimating diffuse solar radiation using skymap

3. Analysing solar radiation results in Suceava

In this research paper was analysed solar radiation in geographical area of Suceava town.
Feature classes: buildings, streets and contours are rigurous organized in a geospatial database.
Solar Radiation module can perform analysis for a landscape or specific location using two methods:
1. Point solar radiation analysis is used to calculate the amount of radiant energy for a given location. Locations can be stored as point features or as x,y coordinates in a location table. Solar radiation calculations can be performed for specified locations only;
2. Area Solar analysis is used to calculate the insolation across an entire landscape.
For diagnostic purposes, it is used the Solar Radiation Graphics tool to create graphical representations of the visible sky (viewshed map), sunmap and skymap. To obtain solar radiation rasters, TIN was generated using contours feature class.

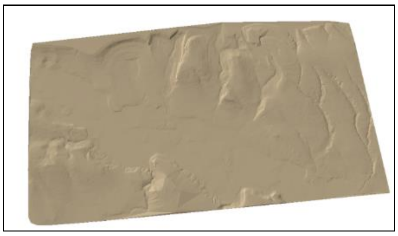

Fig. 4. TIN reveals surface morphology

TIN (Triangular Irregular Network) is a form of vector based digital geographic data and is constructed by triangulating a set of vertices (points) wich offers a digital image of surface morphology.
We can extrude buidings for a better 3D visualization.

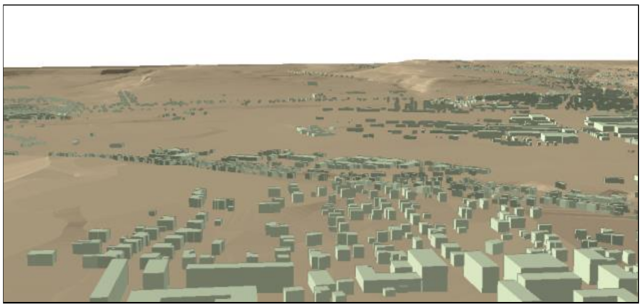

Fig. 5. TIN with 3D buildings

Small differences between TIN's can be noticed, showing fidelity in representing ladforms.

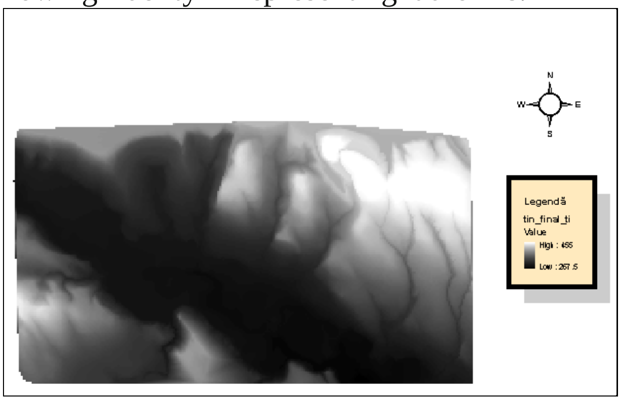

Fig. 6. Showing raster format of TIN

a. Points Solar Radiation

Point solar radiation analysis is used to calculate the amount of radiant energy for a given location. Locations can be stored as point features or as x,y coordinates in a location table. Solar radiation calculations can be performed for specified locations only. We use a landcape raster and buildings shapefile.
I calculated the amount of solar radiation during one year (2014) for analysing maximum and minimum sunlight areas.

Table 1 Buildings insolation during 2014

Attributes of PointsS_solar | Attributes of PointsS_solar

FID	Shape *	T0	FID	Shape *	T0
0	Point	1093188.91648	9909	Point	1052737.34892
1	Point	1093188.91648	9910	Point	1052737.34892
2	Point	1092388.64995	9911	Point	1083182.41115
3	Point	1078456.44452	9912	Point	1099470.93202
4	Point	1078456.44452	9913	Point	1099470.93202
5	Point	1078456.44452	9914	Point	1111648.3451
6	Point	1095774.60964	9915	Point	1094742.95822
7	Point	1095400.47393	9916	Point	1097061.09915
8	Point	1095400.47393	9917	Point	1084539.04206
9	Point	1097993.88388	9918	Point	1083795.94905
10	Point	1097296.25988	9919	Point	1084733.86269
11	Point	1090130.59295	9920	Point	1084733.86269
12	Point	1091282.09134	9921	Point	1085238.61927
13	Point	1090013.54983	9922	Point	1084656.47082
14	Point	1090013.54983	9923	Point	1087405.9171
15	Point	1096250.93043	9924	Point	1087405.9171
16	Point	1090013.54983	9925	Point	1080750.97413
17	Point	1093688.03272	9926	Point	1076352.14373
18	Point	1089360.7842	9927	Point	1080750.97413
19	Point	1091389.61402	9928	Point	1071128.74006
20	Point	1090013.54983	9929	Point	1124333.03062

Record: 1 | Record: 1

b. Area Solar Radiation

Area Solar Radiation derives incoming solar radiation from a raster surface. I used different time configurations for analysing solar radiation: multi-day time configurations with the maximum range of days is a total of one year (2014), special days time configurations and within-day time configurations with the maximum range of time is one day (24 hours).

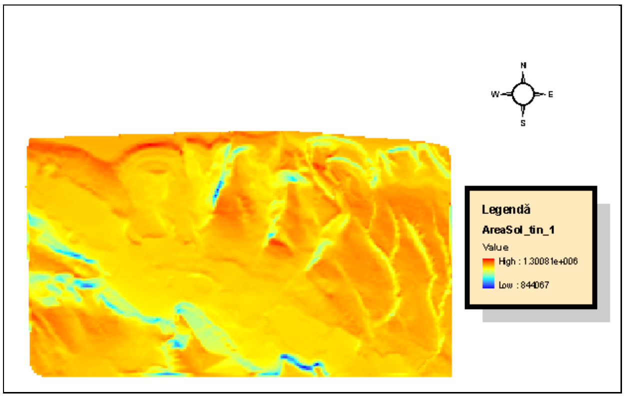

Fig. 7. Area Solar radiation during 2014

We can overlap buildings for analysing shady and sunny buildings:

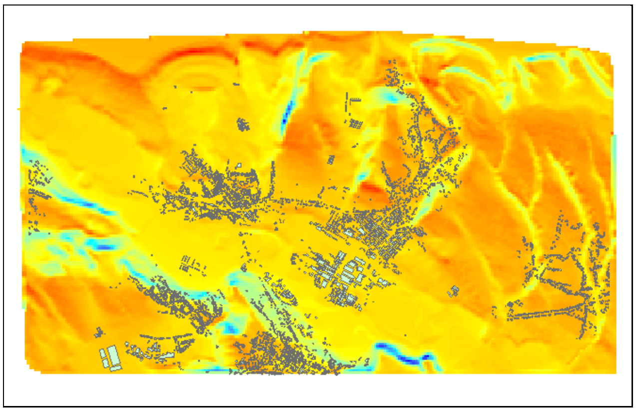

Fig. 8. Overlaping buildings on area solar radiation raster

The red zones shows the maximum amount of insolation are blue ones indicates the minimum amount of insolation for specific locations.

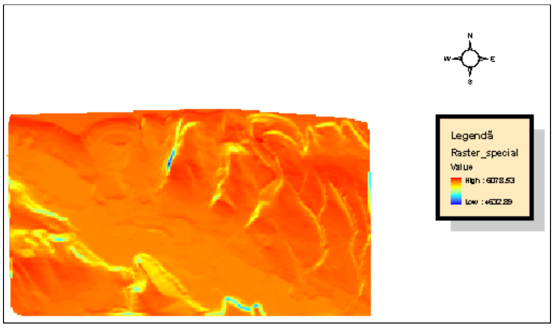

Fig. 9. Special days time configuration rasters

For within a summer day time configuration we can analyse shady and sunny locations.

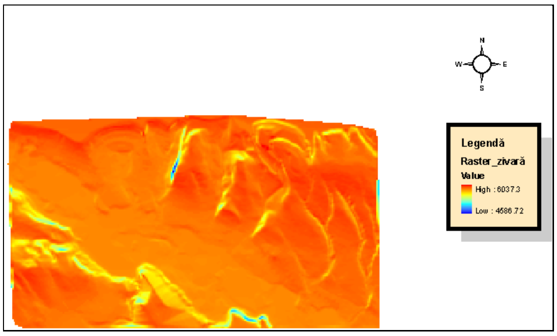

Fig. 10. Within a summer day time configuration raster

c. Solar radiation graphics

Solar radiation graphics Instrument derives raster representations of a hemispherical viewshed, sunmap, and skymap, which are used in the calculation of direct, diffuse, and global solar radiation. In this purpose, I generated viewshed (manipulated in ArcCatalog) with a grey and a white zone. The grey zone indicates obstructions and the white one indicates visibility.

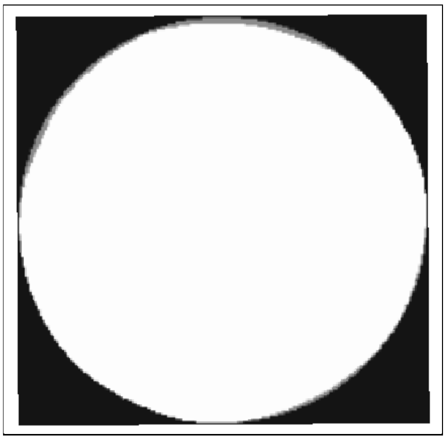

Fig. 11. Hemispherical Viewshed

Optionally we can generate half year time configuration Sunmap and skymap.
I created a half year time configuration sunmap (from January the 5th to June the 9th), with a half hour day time configuration interval.

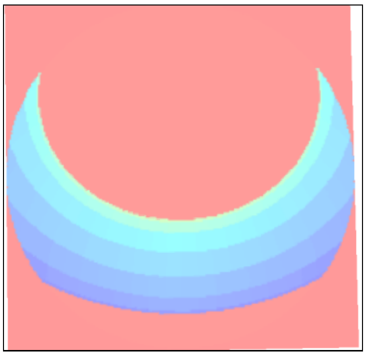

Fig. 12. Half year time configuration Sunmap

I created skymap who has 8 azimutal and zenithal divisions.

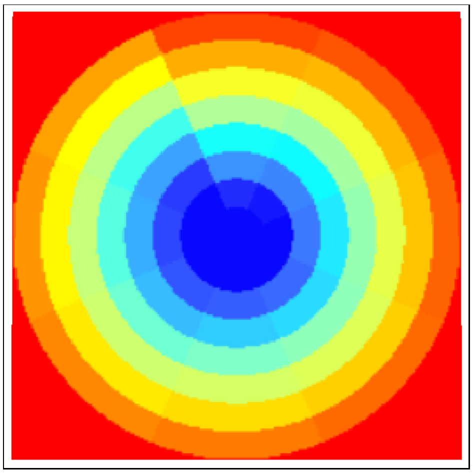

Fig. 13. Skymap

4. Conclusions and further work

The minimum amount of insolation during 2014 has a value of 844067 Wh/m^2 and the maximum one has a value of 13000812 Wh/m^2, the difference between these two values is 456745 Wh/m^2, a major aspect in understanding building design importance.
The average sunshine country exceeds 1250…1350 kWh/m^2. The average sunshine in Suceava is low, indicating the city of Suceava has a low radiation flux from the average country.
This study can be developed in urban branch becouse it seeks to construct buildings as high, so it is necessary a study to analyze solar radiation in large urban centers.
At the same time they are designed buildings that use renewable energy, which requires a study of the slope of the roof (so as to capture the maximum radiation) and the orientation of windows and other elements of the tire.
This study is the starting point in analyzing the effectiveness of installing solar panels or photovoltaic systems in certain areas of a city or regional level.
Carry out studies looked placement of solar panels using a virtual 3D model of a city. Based on this study we cand determine which are the best locations for solar panels and the impact it may have on existing infrastructure.
Insolation is a function of the orientation of the solar panels and the position of the sun in accordance with the surrounding buildings. Thus topography plays an important role in the distribution of solar energy, and must be taken into account rigorously.
In designing the building, it is taking into account the energy that could be absorbed and reflected. These issues provide reliable information on the design penetration of the incident radiation on windows and walls.The designer will have the informations to steer the tire features and choose the materials. Such basic information from Solar Analyst module can be used on the building design programs.
Within a day time configuration with half hour divisions offers the informations of solar radiation variabillity during a day. Solar radiation variation is greater as the sky is cloudy, so in two days sunlight will not have the same value. These short-term analysis of solar radiation may be useful in simulating the performance of photovoltaic panels.
Global and diffuse radiation component and meteorological data are studied to analyze the potential of solar energy in many areas, and Jordan. Over ten years solar radiation were studied monthly using METEONORM meteorological data provided by software to obtain information on the capacity of photovoltaic panels and solar panels, since Jordan has 300 sunny days per year. It can be seen how important is the study of global radiation in the world in studying various processes.
Solar cadastre can be utilized to assess a town's or region's potential for the production of solar power. Additionally, the data can be combined with additional information, e.g. protected historical buildings, in order to further refine the potential analysis. Furthermore, a yearly solar power production can be calculated for single houses and even single roof areas.
This information can be used internally (authorities, power companies) or published in a web application in order to inform house owners and citizens.
GIS software can perform the analysis of solar radiation on different specific elements, also may reveal the potential of solar panels. Both, the electrical and the heat, is analysed in an area of interest, and the potential "green" roofs, which refers to those roofs wich are covered with vegetation.
At a global scale the trend is to use more renewable energy as posible as the earth's resources are limited. The progress of science has made it possible to create a solar house that has the ability to not use electricity or common heating system. The fundamental principle of these houses is storing a huge amount of heat in the earth around them during the summer (high thermal mass HTM) so on winter will no longer need another common system.

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