DOI: 10.31401/WS.2025.proc.29

Study of the Relationship between Solar Radiation and the Level of Geological Hazard

Jelev G.N.

Space Research and Technology Institute, Bulgarian academy of Sciences
gjelev@space.bas.bg

Abstract

The amount of solar radiation (WH/m^2) is an important element in considering all processes on the Earth's surface. The study of the distribution of solar radiation allows mapping and analyzing the effects of the sun and sunlight on a given geographical area for a certain period of time. The modeling of solar radiation is based on the digital elevation model (DEM). It depends on many factors, such as the influence of the atmosphere, latitude and altitude, steepness (slope) and direction of inclination (exposure) of the slope, daily and seasonal changes in the angle of the sun, etc. Mapping the spatial distribution of the amount of solar radiation is useful in a number of fields, such as agriculture, resource management, meteorology, civil engineering, environmental studies, tourism, etc.

This study examines the relationship between the amount of solar radiation, its spatial distribution and geological hazard. The study was conducted on the coastal zone of the Republic of Bulgaria. Bulgaria with a width of 20 km, as an important section of the country's critical infrastructure. A connection has been established between the amount of solar radiation, the relief and the areas with increased geological hazard.

Keywords: solar radiation, geological hazard, digital elevation model, GIS, Remote sensing

1. Introduction

Solar radiation is the primary energy source that drives many of the physical and biological processes on Earth. Understanding its importance for the landscape at different scales is key to understanding a wide range of natural processes and human activities [Choi, et. al. 2019; Dubayah, & Rich, 1995; Fu, & Rich, 2002; Dancheva & Asenovski, 2018; Potužníková et. al. 2023].

When studying different landscapes, topography is a key factor that determines spatial variations in insolation (the amount of direct or total solar radiation reaching the Earth's surface). Differences in elevation, slope orientation (inclination and exposure), and shadows cast by topographic features affect the amount of solar radiation received by different geographic areas. Solar radiation also varies depending on the time of day and year. It contributes to changes in many components of the environment and microclimate, including factors such as: air and soil temperature, evapotranspiration, snowmelt patterns, soil moisture, light available for photosynthesis, photovoltaic parks for energy production, and, last but not least, geological hazard.

Geological hazard summarises natural disasters caused by geodynamic activity or abnormal changes in the geological environment, which usually include internal earth processes such as earthquakes and active faults, and external exogenous geophysical processes such as erosion, abrasion, landslides, debris flows, rockfalls, sinkholes, etc.

The Black Sea coast of Bulgaria is an important part of the country's critical infrastructure, and many of the processes listed above that represent geological hazard occur in this area. This makes it an interesting subject for the present study.

2. Purpose and objectives

The aim of this study is to determine the impact of solar radiation on geological hazard in the country's Black Sea coastal region. The following steps have been outlined to achieve this aim:

– Defining the study area;
– Obtaining basic data and processing it in ArcGIS;
– Analyzing the results.

3. Materials and Methods

An area 20 km inland from the coast was selected as more representative in terms of the processes determining geological hazard and the topographical expression of the relief – DEM for determining solar radiation (Figure 1). It falls entirely within the Black Sea climate region.

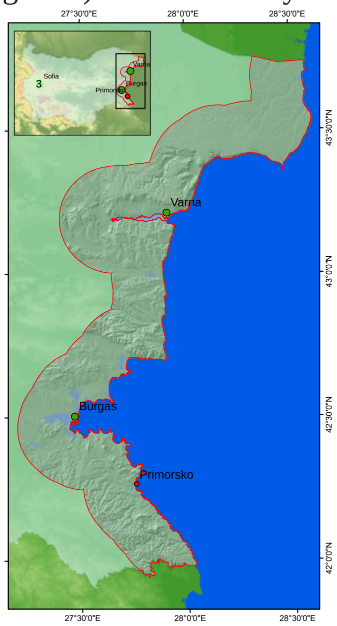
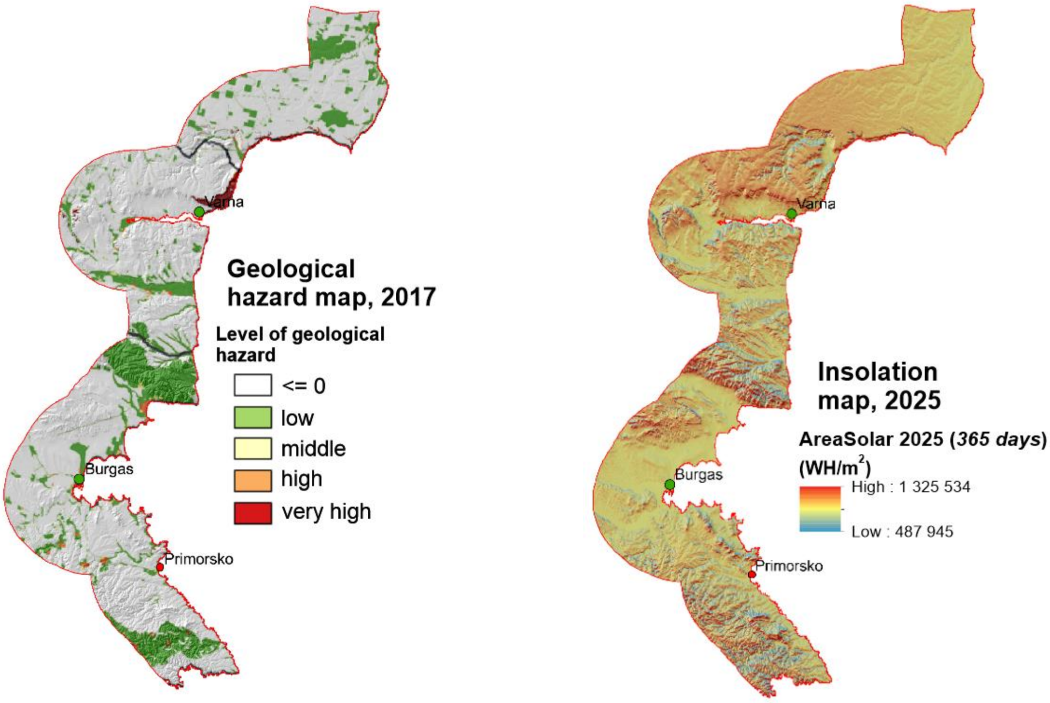


Figure 1. *Study area: Black Sea coastal strip with a width of 20 km from the territory of the Republic of Bulgaria with DEM, Source: [USGS, EarthExplorer, 2025]*

The following basic data were obtained for the analysis: a digital elevation model, coastline and a 20 km buffer inland, a geological hazard map provided by the Ministry of Regional Development and Public Works and compiled by a team from the Geological Institute of the Bulgarian Academy of Sciences [Stage II of ..., 2017, Geological hazard Map ..., 2017] (Figure 2a.). The digital elevation model (DEM) was obtained from the Endeavour space shuttle, the shuttle's radar topography mission (SRTM). The data from this mission is openly available from The U.S. Geological Survey (USGS) [USGS, EarthExplorer, 2025], with elevation information having a spatial resolution of 1 arc second or 30 m. [USGS EROS Archive, 2025].

The coastline was obtained from images from the Sentinel 2 satellite [Sentinel Hub, 2025] under Europe's Copernicus programme. A buffer zone 20 km wide was created inland from the coastline.

The data was processed and analyzed in a GIS database using a number of tools from the ArcGIS software product. The amount of reflected global solar radiation was calculated using the solar radiation analysis tools in ArcGIS, Spatial Analyst - Solar Radiation. Global radiation is calculated as the sum of direct and diffuse solar radiation for each raster cell of the digital elevation model DEM [Dubayah & Rich, 1995; Rich, et. al. 1994; ESRI. ArcGIS Desktop, 2025]. The calculation is repeated for the entire selected area to obtain a map of the insolation of the area (Figure 2b.).



a) *b)*

Figure 2. *a) Geological hazard map, 2017; b) Insolation map, 2025*

4. Results

The global solar radiation analysis feature allows you to map and analyze the effects of the sun on a geographical area for specific periods of time. In this study, the selected period is 365 days (1 year – 2025). The calculations take into account atmospheric effects, the geographical latitude and altitude of the site, the steepness (slope) and geographical direction (aspect), daily and seasonal changes in the angle of the sun, and the effects of shadows cast by the surrounding topography. The output raster represents the global radiation (WH/m^2) or the total amount of incoming solar insolation (direct + diffuse) calculated for each DEM location [ESRI. ArcGIS Desktop, 2025] and is shown in (Figure 2b.).

The Bulgarian Black Sea coast is slightly indented with a fractal dimension of 1.11 and a curvature of 2.41 [Jelev, 2023]. The geological base of the Earth's surface has a diverse rock composition. The relief has developed mainly under the influence of internal Earth forces. This determines the presence of various abrasive and accumulative forms on the Earth's surface – cliffs, beaches, etc.

Four more characteristic areas have been selected. The northern part of the studied territory is the *Dobruja* coastal zone [Dimitrov, 2023] (Figure 3.1). There, the relief is flat and the amount of solar radiation is very high. In this section, the geological hazard is zero or very low. An exception is the coastal zone in the southern part of the section, where cliffs prevail.

In the next area (Figure 3.2), the terrain is rugged and part of the *Frangenska* coastal zone. The section is subject to the strong influence of a number of hazardous geological processes and, in combination with high anthropogenic pressure, local areas with high and very high geological hazard are formed. Global solar radiation is differentially distributed. It is high in the flat and hilly areas and low in the deep valleys and north-facing slopes.

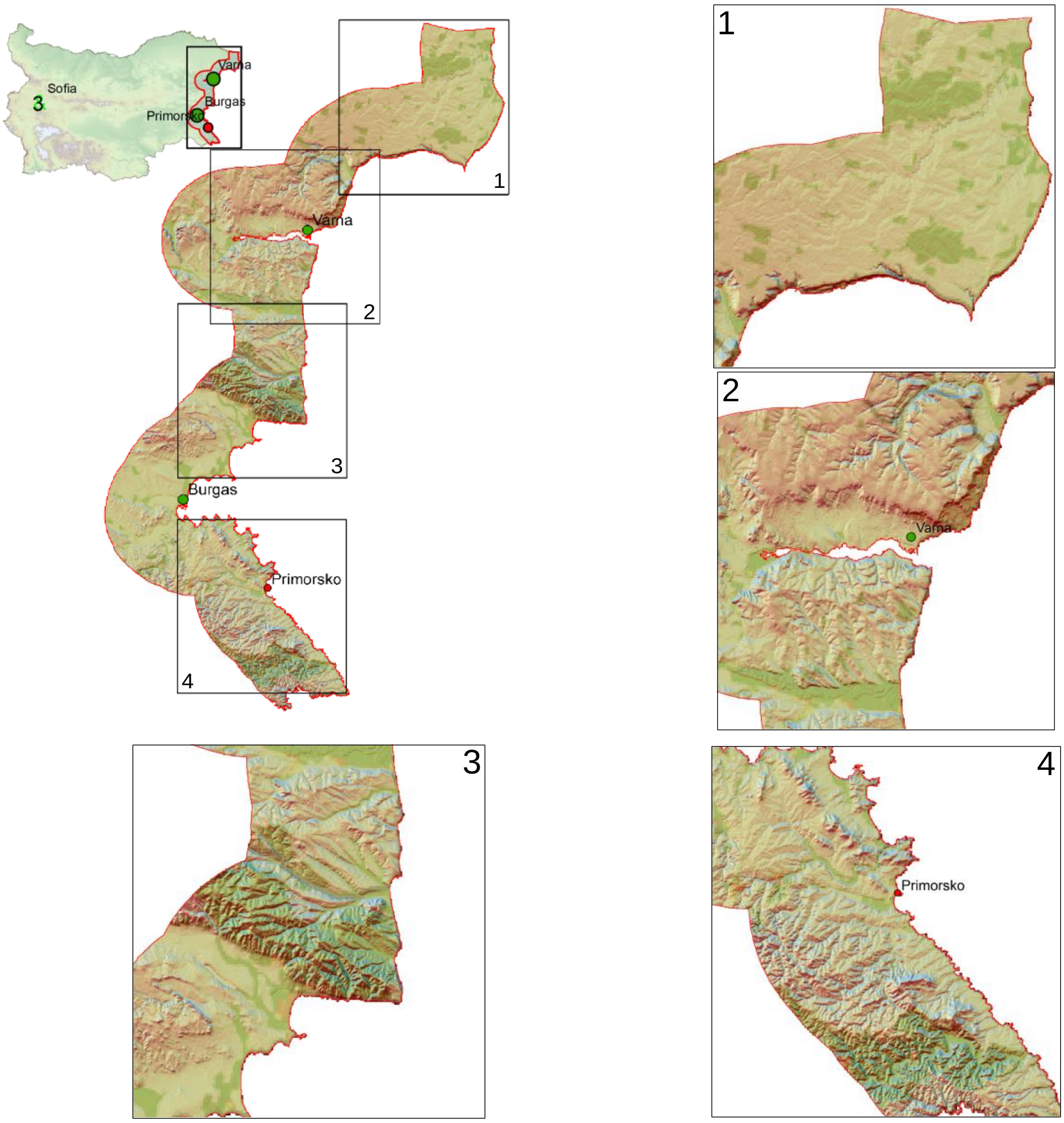


Figure 3. *Composite map of correlation between global solar radiation and geological hazard in the studied area*

Section 3 (Figure 3.3) covers the *Stara Planina* coastline. Morphologically, clearly defined accumulation forms (sand strips) have been formed along the coastline at the foot of the prevailing cliffs. In this section, the geological hazard is low to medium and is most widespread. Global solar radiation is directly related to the east-west oriented relief forms. High values prevail in the flat areas and southern slopes, while low values prevail in the northern slopes and deeper valleys. The southern part of the section falls within the Burgas coastal zone, where areas with accumulative landforms prevail. In this area, the geological hazard is locally distributed. Global solar radiation is very high, with the exception of some northern slopes.

The fourth section (Figure 3.4) is characterized by a highly indented coastline with numerous bays and peninsulas. This section falls within the *Strandzha* coastal strip. Abrasion processes prevail, shaping the characteristic type of coastline. They are the result of the strong impact of internal and external geological forces on erosion-resistant rock complexes. The geological hazard is represented in the southern part of the section as being low. In some areas, it is moderate to high. The rugged terrain determines the uneven distribution of global solar radiation. Its distribution is patchy, with rapid alternation between low and high values.

5. Conclusion

The calculation of global solar radiation and some of the factors influencing the determination of geological hazard is based on the use of a digital terrain model and its derivatives – slope, exposure, curvature, etc. This also determines the relationship between geological risk and global solar radiation.

Acknowledgments

This work was supported by the NSP DS program, which has received funding from the Ministry of Education and Science of the Republic of Bulgaria under the grant agreement no. Д01-74/19.05.2022.

References

Choi, Y., Suh, J., Kim, S.-M. (2019). GIS-based solar radiation mapping, site evaluation, and potential assessment: A review, *Applied Sciences*, Vol. 9, 1960, DOI: 10.3390/app9091960.

Dancheva, A., Asenovski, S. (2018). Study of waste disposal thermal radiation using satellite data and considering solar influence, *Aerospace Research in Bulgaria*, Vol. 30, pp. 16–25, DOI: 10.3897/arb.v30.e02.

Dimitrov, L. (2023). *Morski prostranstven plan na Republika Bulgaria 2021–2035*, Tom 2: Geologiya i geomorfologiya. Available at: https://www.mrrb.bg/bg/morski-prostranstven-plan-na-republika-bulgariya-2021-2035-g/ (in Bulgarian).

Dubayah, R., Rich, P.M. (1995). Topographic solar radiation models for GIS, *International Journal of Geographical Information Systems*, Vol. 9, No. 4, pp. 405–419, DOI: 10.1080/02693799508902046.

Ďuračiová, R., Pružinec, F. (2022). Effects of terrain parameters and spatial resolution of a digital elevation model on the calculation of potential solar radiation in the mountain environment: A case study of the Tatra Mountains, *ISPRS International Journal of Geo-Information*, Vol. 11, No. 7, 389, DOI: 10.3390/ijgi11070389.

ESRI. *ArcGIS Desktop – An overview of the Solar Radiation toolset*. Available at: https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/an-overview-of-the-solar-radiation-tools.htm (accessed 2025).

ESRI. *ArcGIS Desktop – Area Solar Radiation*. Available at: https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/area-solar-radiation.htm (accessed 2025).

ESRI. *ArcGIS Pro – How solar radiation is calculated* (Documentation). Available at: https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-solar-radiation-is-calculated.htm (accessed 2025).

Fu, P., Rich, P.M. (2002). A geometric solar radiation model with applications in agriculture and forestry, *Computers and Electronics in Agriculture*, Vol. 37, pp. 25–35.

Jelev, G. (2023). Using remote sensing data and GIS in research of morphometric characteristics of the coastal area in Bulgaria, *Aerospace Research in Bulgaria*, Vol. 35, pp. 16–27, DOI: 10.3897/arb.v35.e02.

Karta na geolozhkiya risk v Bulgaria, scale 1:1,300,000 (2017). Available at: http://gis.mrrb.government.bg/KGR/02%20maps/Risk.pdf (accessed 2025) (in Bulgarian).

Kausika, B.B., van Sark, W.G.J.H.M. (2021). Calibration and validation of ArcGIS solar radiation tool for photovoltaic potential determination in the Netherlands, *Energies*, Vol. 14, 1865, DOI: 10.3390/en14071865.

Potužníková, K., Koucká Knížová, P., Chum, J., Podolská, K., Kouba, D., Mošna, Z., Georgieva, K., Bojilova, R., Kirov, B., Asenovski, S. (2023). Summer tropospheric mesoscale situations with impact on the ionospheric plasma, *Proceedings of the Fifteenth Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere"*, ISSN 2367-7570, pp. 89–97, DOI: 10.31401/WS.2023.proc.

Rich, P.M., Dubayah, R., Hetrick, W.A., Saving, S.C. (1994). Using viewshed models to calculate intercepted solar radiation: Applications in ecology, in: *American Society for Photogrammetry and Remote Sensing Technical Papers*, pp. 524–529.

Sentinel Hub by Planet Labs. *EO Browser*. Available at: https://www.sentinel-hub.com/eo-browser/ (accessed 2025).

USGS EROS. *Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global* (Digital Elevation). Available at: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1.