XII National and y III International

Conference on Engineering Thermodynamics

Comparison of spatial interpolation methods for the estimation of solar potential in Castilla y León

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Keywords: *GIS; global horizontal irradiation; IDW; kriging; spatial interpolation*

TOPIC: NUMERICAL SIMULATION AND MODELLING

1. Introduction

Solar radiation is one of the most relevant and influential climatic variables in the interactions of the Earth System, as it is a determining factor for the development of many processes and disciplines in different fields such as agriculture, transport, architectural design, or renewable energies. Among renewable energies, one of the most representative is solar energy. Many countries, such as Spain, have a high potential for photovoltaic energy production. For some years now, research has been carried out on designing and implementing these systems in an integrated way to maximise their use [1,2]. The spatio-temporal distribution of Global Horizontal Irradiance (GHI) and other variables derived from it, such as Photosynthetically Active Radiation (PAR), provide valuable information as it can be used, among other things, to estimate plant growth or to prevent environmental or biological risks [3].

Maps have been used for thousands of years, but it is only in the last decades that the combination of mapping with computer graphics and databases has been developed to create Geographic Information Systems (GIS) [4]. Mapping is very interesting for integrating and analysing spatial information to obtain a continuous surface from irregularly distributed point data when the objective is to get regional scale values [5]. The use of historical GHI data from weather stations allows a very accurate assessment of the behaviour of the solar resource. However, the high cost of operation and maintenance makes them scarce and widely distributed, often making data collection difficult. The accuracy of measurements also depends on sensors, calibration methods, and data quality analysis.

Nevertheless, it is possible to map a variable on a continuous surface with spatial interpolation methods and GIS [6]. Interpolation consists of filling in the gaps between sample observations to produce a grid of values [7]. These techniques are used to assess, estimate and study the spatial characteristics of site-dependent variables [8] to produce a continuous surface that can be represented on maps at different spatial scales [9]. There are two types of interpolation techniques: local interpolators and geostatistical methods. Local interpolations only use climate data from the nearest weather stations and produce surfaces based on measured points or mathematical formulas. On the other hand, geostatistical interpolations are based on statistics and are used for more advanced prediction by modelling surfaces, which also consider other factors such as distance points, anisotropy, and spatial variability [8].

Using different techniques on the same initial data can produce very different results. Ideally, an interpolation technique should be accurate, robust, flexible enough to handle large and varied datasets with inputs errors, computationally efficient, and easy to use, but no existing method can satisfy all these conditions [7]. For this reason, it is necessary to test different interpolation techniques and analyse which one is the best suited for the study dataset, as each method has advantages and disadvantages.

The main objective of this study is to make a comparison between different interpolation methods and decide which are the most suitable for estimating GHI in Castilla y León (Spain).

2. Materials and method

Castilla y León is the largest region of Spain, with a surface area of 94,224 km^2, equivalent to almost 20% of the total national territory. A broad plateau approximately 800 metres above sea level covers the region. It is located inland northwest of Spain, surrounded by three mountain systems (Cordillera Cantábrica to the north, Cordillera Central to the south, and Sistema Ibérico to the east). As a result, its climate is mainly temperate.

Considering the great variety of topographic and climatic characteristics of the region, we worked with half-hourly (W/m^2) and daily (MJ/m^2) GHI data from 46 stations of Castilla y León registered over a period of 14 years (2007-2020) from the 'Sistema de Información Agroclimática para el Regadío' (SiAR network) [10]. These 46 stations were selected among the 53 total ones because more than 12 years of data are available (a valid year being understood as a year with more than 330 daily values) and because after calculating the daily values from the half-hourly ones by integration with the trapezoid method [11], they do not differ more than 0.02 MJ/m^2 with respect to the daily values [12]. The pyranometers used by the SiAR network to measure solar radiation have an accuracy of 3% [10]. Therefore, the daily mean GHI was calculated for each year of the study period to obtain the final 14-year average for each station. Finally, an annual daily mean value of GHI (MJ/m²) were assigned to each weather station. With the aim of making the interpolations as accurate as possible, data from 49 other stations belonging to all neighbouring regions (SiAR network, ADRASE, Air Quality Control Network in Cantabria, and SOLARGIS) [13] were included. All these data were analysed and then filtered using conventional quality criteria [14].

The annual daily mean values were used to perform two types of interpolation with QGIS 3.16 software: local interpolators (inverse distance weighting (IDW), natural (NaN) and nearest neighbour (NN), thin plate splines (TPS), B-spline (BS), and multilevel B-spline (MBS)) and geostatistical methods (ordinary kriging (OK), simple kriging (SK), and universal kriging (UK)) [15,16].

Four control treatments were selected to assess the accuracy of the interpolation techniques. In each treatment, the six weather stations in Castilla y León (test set) shown in Figure 1 were removed for interpolation and used for evaluating the error of the different methods.

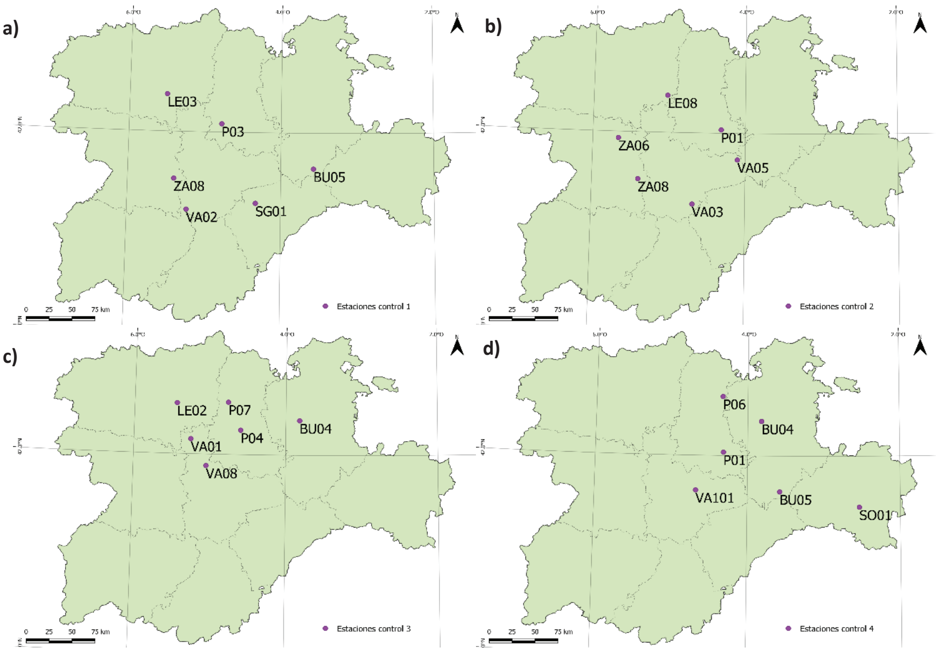

Figure 1. Location of the stations of each control treatment. a) Control 1; b) Control 2; c) Control 3; d) Control 4.

Interpolation methods were evaluated by calculating three common statistical errors: The Root Mean Square Error (RMSE), the Mean Bias Error (MBE), and the Mean Absolute Error (MAE) defined by Eqs. 1-3.

$$nMBE = \frac{1}{GHI_{exp}} \frac{\sum_{i=1}^{n}(GHI_{int} - GHI_{exp})}{n} \cdot 100\ (\%) \tag{1}$$

$$nRMSE = \frac{1}{GHI_{exp}} \sqrt{\frac{\sum_{i=1}^{n}(GHI_{int} - GHI_{exp})^2}{n}} \cdot 100\ (\%) \tag{2}$$

$$nMAE = \frac{1}{GHI_{exp}} \frac{\sum_{i=1}^{n}|GHI_{int} - GHI_{exp}|}{n} \cdot 100\ (\%) \tag{3}$$

Where n is the number of weather stations used in each control, GHI_{int} are interpolated GHI values and GHI_{exp} are experimental GHI values.

3. Results and discussion

The GIS maps were coloured according to the different solar radiation levels. Thus, locations with higher GHI levels are indicated by colours closer to red and the colour transitions to blue as the radiation levels decrease. The general trend is an increase in radiation levels as we move southwards in the region, even so, the annual daily mean values of GHI in Castilla y León are quite homogenous as most of them are between 15 and 16 MJ/m². Except for the stations of Santa Gadea del Cid and Vadocondes, both in the province of Burgos, which register the lowest values, 12.19 and 13.86 MJ/m², respectively. The highest values were recorded by two stations: Arabayona in Salamanca and Finca Zamadueñas in Valladolid, these being 17.21 and 17.11 MJ/m², respectively.

As shown in Table 1, kriging and splines interpolation techniques provided the best estimates in the four controls with low values of nRMSE, nMBE and nMAE. Figure 2 shows the ordinary and simple kriging representation, as they have the lowest errors in controls 1 and 2.

Table 1. Lower error rate of the interpolation methods. Comparison of the annual daily mean GHI values for the whole study period at six stations (n=6 in Eq. 1-3) in each control.

Treatment	**nRMSE (%)**	**nMBE (%)**	**nMAE (%)**
Control 1	6.269 (Ordinary kriging)	0.027 (Ordinary kriging)	1.290 (Ordinary kriging)
Control 2	2.354 (Simple kriging)	-0.248 (Simple kriging)	0.491 (Simple kriging)
Control 3	4.273 (B-spline)	-0.048 (Thin Plate Splines)	0.878 (B-spline)
Control 4	3.827 (Thin Plate Splines)	0.026 (Universal kriging)	0.775 (Thin Plate Splines)

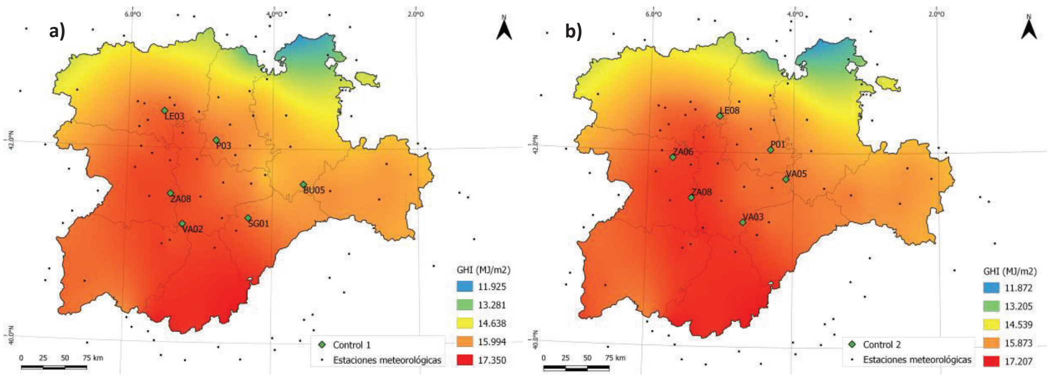

Figure 2. Interpolated annual daily mean GHI (MJ/m²) values for the whole study period in Castilla y León. a) Ordinary kriging; b) Simple kriging.

Similar studies were carried out in Spain. Gutiérrez-Corea *et al.* [17] used sub-hourly GHI observations over mainland Spain and Balearic Islands from three stations networks. They also applied several interpolation methods, including IDW and OK, but the area was so large that the differences between the two methodologies were not revealing. Alsamamra *et al.* [6] obtained the best fit in Andalusia with the OK interpolation technique for their monthly data with RMSE ranging from 6.2 to around 11.2% and MAE from 2.3 to 6%. Urraca *et al.* [18] conducted their study in Castilla La Mancha comparing the OK interpolation method with two models (parametric and statistical) and two datasets (satellite-based and reanalysis) with OK as one of the best performing methods overall. Rodríguez-Amigo *et al.* [12] also found that kriging interpolation techniques were the best spatially representative of the GHI variable in Castilla y León.

However, the reliability of the interpolation techniques is reduced with local interpolators. In our study, the worst results were given most often by the IDW and NN method (Table 2) (Figure 3). Other authors [3,16] have also indicated in their studies that the worst-performing interpolation methods were IDW and NN.

Table 2. Highest error rate of the interpolation methods. Comparison of the annual daily mean GHI values for the whole study period at six stations (n=6 in Eq. 1-3) in each control.

Treatment	nRMSE (%)	nMBE (%)	nMAE (%)
Control 1	12.787 (Thin Plate Splines)	1.561 (IDW)	2.550 (Thin Plate Splines)
Control 2	7.845 (Nearest Neighbour)	0.965 (Nearest Neighbour)	1.510 (Nearest Neighbour)
Control 3	10.198 (IDW)	1.828 (IDW)	2.068 (IDW)
Control 4	8.427 (IDW)	4.964 (Simple kriging)	4.744 (Simple kriging)

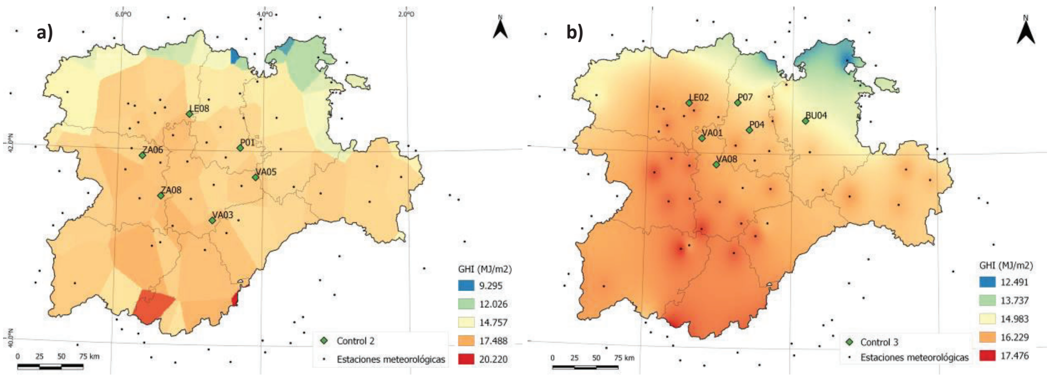

Figure 3. Interpolated annual daily mean GHI (MJ/m²) values for the whole study period in Castilla y León. a) Nearest Neighbour; b) IDW.

4. Conclusions

Interpolation methods are well known in the spatial representation of different variables. In an area as extensive and with an orography as varied as that of Castilla y León, it was necessary to have a large set of quality data. In general, it is difficult to select the best interpolation method as its accuracy changes depending on the data and its spatial structure. In particular, kriging techniques can provide reliable estimates of climate variables such as solar radiation, although the reliability of the estimates may be diminished if complex topographic areas are involved.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Spanish Ministry of Science & Innovation under the I+D+i state program “Challenges Research Projects” (Ref. RTI2018-098900-B-I00). Elena Garrachón-Gómez thanks financial support provided by Junta de Castilla y León (Programa Operativo de Empleo Juvenil, Fondo Social Europeo e Iniciativa de Empleo Juvenil).

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