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Performance comparison of two global solar radiation models for spatial interpolation purposes

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ABSTRACT

In this paper, two monthly global solar radiation spatial interpolating models: an Artificial Neural Network (ANN) and an Inverse Distance Weighting based model (IDW) have been developed and evaluated. The purpose is to predict the Global solar radiation within a distance of more than 50 km. The ANN model uses the available meteorological data in the targeted region while the IDW model uses the global solar radiation measured in the neighboring regions. To construct and validate the models, we have collected for 5 consecutive years (2008–2012), the monthly values of 5 different meteorological parameters from 10 meteorological stations located in the south and center of Tunisia. The obtained outcome of the two model evaluation gives results that are comparable.

For the developed ANN model, the average relative root mean square error recorded is 6.4%, while for IDW model, it amounts to 5.11%. The IDW model is easier to implement and slightly more precise than the ANN model.

This study investigated the behavior of the two models for different climate conditions through two scenarios. The outcome indicates that the number of samples that the ANN will be trained with to predict the GHI is more significant than the climatic conditions from where these samples are retrieved. However, presenting input data from sites which have a climate condition similar to that of the predicted region increases the accuracy of the IDW model.

1. Introduction

The conversion of solar energy into thermal or electrical energy is performed by solar power plant. A good knowledge of the availability of solar radiation in the place of settlements of a solar power plant plays a crucial role in the design phase of the solar technology and accelerates its deployment by reducing the investment decision uncertainty [1]. The daily, monthly and yearly potential of the global solar radiation (GHI) can either be measured with a high-cost equipment or computed using solar radiation models. In most cases, the targeted site is not covered by measuring stations, especially in the inhabitable desert regions, despite their outstanding potential to get high scale solar power plants. In fact, such measuring stations are commonly found in the surrounding area within a distance of more than 50 km [2].

A wide variety of GHI models have been reported in the literature, ranging from simple empirical models [3–7] such as the Angstrom model to interpolation models [8–10] like inverse distance weighting models, and recently, to computational artificial intelligence techniques [11–13].

Besharat [14] reviewed 78 empirical models by classifying them into four categories: cloud-based models, sunshine duration based models, temperature based models and other meteorological parameters based models. Besharat used these models to estimate the monthly GHI in Yazd city (Iran). He claimed that ELMetwally-Angstrom sunshine duration based model [15] is the most precise model with a relative root mean square error (rmse) equal to 0.5385 $MJ/m^2/day$.

The inverse distance weighting models (IDW) utilize the measured GHI at the neighboring site and the relative distance in order to conduct estimation in a region of interest.

Many Inverse distance weighting models have been developed in the literature; the major difference between them is in the definition of the effective relative distance. This distance was historically presented as equal to the geodetic distance [16] and then it was developed by introducing some geographical factors such as the altitude [17] or other additional geographic and climatic parameters. Lefevre [8] tested different Inverse Distance Weighting models by adding new factors in the effective distance expression which take into account the effect of the latitude, the orography and the presence of water bodies. He applied

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the developed models to predict the monthly GHI over 586 European stations. The results of prediction were compared to measurements. The lowest relative root mean square error (rmse%) was equal to 8%.

The existing intelligence techniques such as Artificial Neural Networks [18–21], Neuro-Fuzzy model [22–24] and genetic algorithm [25,26] use the meteorological and atmospheric parameters like temperature, evaporation, sunshine duration, wind speed, relative humidity and the GHI measurements for the training procedure of these models. After training, the models can predict the global solar radiation at sites not equipped with GHI measuring instruments.

The Neurofuzzy model was tested by Olatomiwa [22] to predict the solar radiation over Nigeria. The model uses the sunshine duration and the monthly mean, maximum and minimum temperature as input parameters. The comparison with measurements revealed an rmse equal to 0.656 $MJ/m^2/day$.

Genetic algorithms were tested by Demirhan [25] to estimate the yearly and monthly global solar radiation in Turkey. Demirhan developed and validated the models using 65 site measurements of global solar radiation and meteorological parameters. The mean absolute error (MAPE) of the prediction varied from 0.71 to 3.26 $MJ/m^2/day$.

The artificial neural network (ANN) has been widely investigated to estimate the monthly and daily global solar radiation in sites where no measurements are available [27,28].

Alsina [29] constructed an ANN model using 45 meteorological stations located in Italy in order to predict the global solar radiation. The results of estimation were compared to site measurements. The absolute mean percentage error (MAPE) ranged from 1.67% to 4.25%.

Chiteka [30] used the geographical and meteorological data to train and test an ANN model in order to predict the global solar radiation in several places in Zimbabwe. Compared to measurements, the results of the model prediction achieved a root mean square error of 0.223 $kWh/m^2/day$.

Al-Shamisi [31] developed an ANN model to estimate the monthly mean global solar radiation in Abu Dhabi (United Arab Emirates). The model was trained using 16 years (1993–2008) of measurement database. The maximum daily temperature, mean daily wind speed, mean daily sunshine hours and mean daily relative humidity were used as input parameters to the model. The results of prediction were compared to 5 years (2004–2008) of measurements. The obtained relative mean square error (rmse) and mean bias error (mbe) were respectively equal to 0.293 kWh/m^2 and 0.019 kWh/m^2.

Over the last few years, the artificial neural network model has gained a good reputation towards GHI prediction compared with the other computing methods and intelligence technique models [32].

Zou [33] compared an ANN model with two empirical models (Angstrom-Prescott model and Bristow-Campbell) to estimate the daily global solar radiation in southern China. The ANN model uses the sunshine duration, the relative humidity, the mean, maximum and minimum temperature, the precipitation, the air pressure, the water vapor pressure and the wind speed as input parameters. The models were evaluated using site measurements. The results showed that the neural network is the most accurate model to predict GHI, the root mean square error (rmse) was equal to 1.34 $MJ/m^2/day$. The rmse of Angstrom-Prescott model was equal to 2.65 $MJ/m^2/day$ while it was equal to 2.19 $MJ/m^2/day$ for the Bristow-Campbell model.

Mehdizadeh [34] compared the results of the ANN, 2 intelligence technique models (Neuro fuzzy system Interference: ANFIS and Gene Expression Programming model: GEP) and 48 empirical models to ground measurements in order to estimate the daily global solar radiation in Kerman region (Iran). The ANN model uses the sunshine duration, the relative humidity, the ambient temperature, the atmospheric pressure and the extraterrestrial solar radiation as input parameters. The error results of the ANN models in terms of Mean Absolute Error (MAE = 1.184 $MJ/m^2/day$) are more precise than the ones of the GEP model (MAE = 1.246 $MJ/m^2/day$), ANFIS model (MAE = 1.24 $MJ/m^2/day$) and the 48 empirical model (lowest MAE = 1.279 $MJ/m^2/day$).

By varying the number of neurons and the training algorithm, Azadeh [35] developed several artificial neural networks in order to estimate the monthly global solar radiation in Iran. He compared the developed ANN with an Angstrom model and showed that the developed ANN model achieved the highest precision of estimation. The ANN and the Angstrom model recorded respectively a mean relative error of 7.5% and 14.78%.

Jiang [36] developed 6 empirical models and an ANN model to predict the monthly global solar radiation in 8 Chinese regions. All the developed models used the same input parameters, which were: the altitude, the latitude and the sunshine duration. Jiang showed that the ANN model is more accurate than the empirical models. The ANN model predicted the GHI with a root mean square error equal to 0.867 $MJ/m^2/day$ while the empirical models performed GHI prediction with an rmse varying from 1.09 to 2.508 $MJ/m^2/day$.

Most of the ANN performances are generally compared to simple empirical models such as Angstrom models or other varieties of simple empirical and regression models [37]. Kumar [38] reviewed the literature by comparing 13 regression models with 19 ANN models. He showed that the ANN model gives more accurate results then the regression models and could be an alternative solution to predict the solar radiation. Khatib [39] reviewed the comparison of the ANN models with a linear, nonlinear and fuzzy logic models.

All the results of the comparison show the accuracy of the ANN model compared to all the empirical models to predict the global solar radiation. However, most of the ANN comparison attempts have been performed with models that use meteorological data as inputs, but few studies compare the ANN model with models that do not require meteorological input parameters such as the inverse distance-weighting model (IDW). Indeed the meteorological data may not be available for all the desired regions which makes the IDW model very appropriate to be implemented in order to perform global solar radiation prediction in an unknown site. Besides, many studies have been performed on optimizing the ANN models by searching the most relevant ANN input parameters [40] or selecting the best configuration of the ANN structure [29] but none has dealt with the effect of the climate on the behavior of the ANN models. To have a clearer view about the relative performance of the ANN models toward spatial interpolating models, we developed and compared the Artificial Neural Network (ANN) and the Inverse Distance Weighting interpolating model (IDW) implemented in Tunisian desert regions. In addition to this, the paper investigated the behavior of these two models for different climate conditions.

As a result of investigations, this paper aims to compute the GHI in the Tunisian desert regions. Indeed, despite being a part of the Sun Belt area, known by the economic viability of solar projects [41], Tunisia does not yet have GHI stations covering all its desert regions. Even with the few existing meteorological stations in these areas, there are gaps of measurements caused mainly by the equipment maintenance. Furthermore, the existing attempts of GHI prediction in Tunisian terrain are particularly limited, which makes such investigation a fruitful area for further work.

Given the importance of the knowledge of the solar energy availability and the absence of measuring stations in such regions, this study set out to evaluate and compare the use and the accuracy of an artificial neural network and an inverse distance weighting model in order to spatially interpolate the global solar radiation. The main objective was, thus, to select the most accurate and appropriate model and to give some recommendations as regards the use of these two models in order to effectively estimate the global solar radiation.