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Research Article

An Spatial Analysis of Insolation in Iran: Applying the Interpolation Methods

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Abstract

This study aims to spatially analyze the insolation in Iran region. Insolation data are gathered from of Atmospheric Science Data Center of NASA – SSE data set. In this study, interpolation methods are used to spatially analyze the monthly, seasonal, and annual insolation. In this study various method such as IDW, RBF (completely regularize spline, spline with tension, multiquadric, inverse multiquadric, thin plate spline) and simple kriging (spherical, circular, exponential, Gaussian) are evaluated through cross validation. Next, the methods that predict the insolation with less error are verified by applying RMSE. The results reveal that RBF predicts the amounts of monthly, seasonal, and annual insolation with higher precision. The results, after applying the spatial analysis, reveal that in Iran region the southwest, south, and parts of the center receive the highest levels of annual insolation. These regions also show the lowest coefficient of variation. The lowest levels of insolation and the highest coefficient of variation are recorded for north and parts of northwest.

Keywords: *Renewable energy, Solar energy, Insolation, Spatial analysis, Interpolation methods.*

1. Introduction

Nowadays taking advantage of renewable energy seems necessary due to the limitation of fossil energy resources as well as the increasing pollution caused by their excessive utilization. Solar energy is considered as one of the most significant renewable types of energy because it is environmentally friendly and would cause minor, if any, pollution; it is unlimited and endless; and it is available in all countries which could be utilized wither regionally or locally. For optimal utilization of solar energy, we need to know the quantity of the radiation received by the earth in various points along the specific geographic region. In other words, optimal utilization of the solar energy is possible through spatial analysis of insolation (income solar radiation).

The considerable significance of solar energy has given rise to a range of experimental models for assessing the amount of solar radiation. In the majority of the proposed experimental models, the climate's parameters are applied to assess the amount of solar radiation. Angstrom (1924) suggests that there is a linear relationship between transmissivity of atmosphere and potential day length (regard to the ratio of sunshine hours available to maximum sunshine hours) (Kamali and Moradi, 2004). Considering the cloudiness, Black (1956) proposes a uni-variable and non-linear relationship for assessing the global radiation (Khalili and Rezayisadr, 1997). Sabbagh and his colleagues (1977) used the variable including sunshine hours, minimum temperature, and relative humidity to estimate the daily global radiation (Sabbagh, *et al*, 1997). Bristow and Campbell (1984) employed the variables such as the sunshine hours, the minimum and maximum temperatures and daily precipitation for estimating the daily global radiation (Kamali and Moradi, 2004). Yang and his colleagues (2006) drew on the variables such as the surface pressure, global distribution of ozone thickness, precipitable water, the global distribution of Angstrom turbidity, and the sunshine hours for estimating the amounts of hourly, daily, and monthly radiation (Yang, *et al*, 2006).

2. Material and method

This study aims to offer the spatial analysis of insolation in the geographic region of Iran. The procedures for the study are presented in Figure 1:

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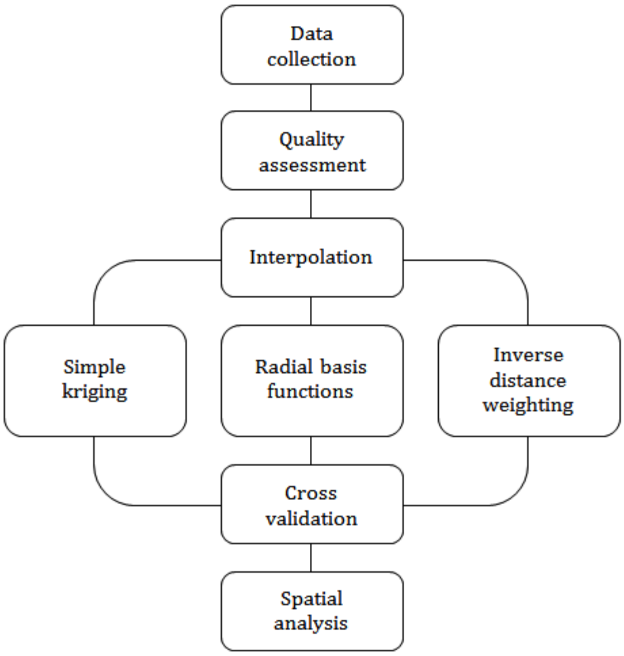


Fig.1 The procedure of study

2.1 Data collection and quality assessment

As the procedure of the present study includes, first the insolation is measured in a number of Iran's synoptic stations. As the next step, the quality of the collected data is evaluated in Tehran Institute of Meteorology and Atmosphere Sciences in two stages. In the first stage, the data are controlled according to the maximum and minimum possible amounts; that are zero and top of atmosphere radiation. Afterward, the quality of data is controlled with regard to the ratio of sunshine hours to maximum sunshine hours or potential day length. Finally, the obtained results reveal that in all of Iran's radiometry stations more than half of the data are dubious and they should undergo a complete quality control. The results of quality assessment for the data are summarized in Table 1.

In the present study, the satellite data are used for spatial analysis of the insolation in Iran region. These data are gathered from of Atmospheric Science Data Center of NASA – SSE (Surface meteorology and Solar Energy) data set. The geographic region under study includes the latitudes of 25-40 northern degree and the longitudes of 45-63 Eastern degree (Fig.2). The time span for this study includes 1983-2005.

The quality of the satellite data are evaluated through regression analysis. The amount of RMSE (Root Mean Square Error) and the amount of bias (by which the average of a set of amounts moves away from the reference amount) are calculated as 13.94 and -2.22 respectively. The obtained numbers show that the data possess fairly high quality.

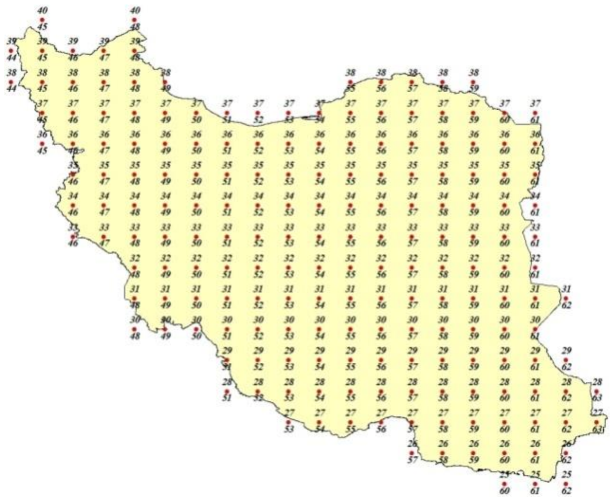


Fig.2 The geographic region under study and the sampled points

Table 1 The results of quality assessment for data of Iran radiometry stations

Radiometry stations	Total data	Dubious data according to the zero and top of atmosphere radiation	Dubious data according to the potential day length
Oroomieh	4928	37	1617
Esfahan	5466	51	2080
Bojnurd	5412	219	1934
Bushehr	2268	37	591
Tabriz	3906	86	1490
Tehran	5450	513	1601
Jask	4223	116	2010
Khoorbiabanak	4228	12	1252
Ramsar	6075	387	1856
Zahedan	5459	567	1592
Zanjan	5778	32	2274
Shiraz	4574	43	2247
Tabass	4995	67	2165
Karaj	3013	198	820
Kerman	5664	35	2892
Kermanshah	5964	43	2477
Mashhad	6731	67	2838
Hamedan	4102	82	1357
Yazd	3607	52	1119

Kamali and Moradi, 2004

2.2 Interpolation methods

Interpolation methods are used in this study to analyze the insolation spatially in the region of Iran. Interpolation refers to the process of estimating the unknown points according to the amounts of sample points (Sanjari, 2011). The interpolation methods are divided into two categories of exact or deterministic and approximate or geostatistic. In the exact or deterministic methods the interpolated surface passes through the sampling points; similar to IDW (Inverse Distance Weighting) and RBF (Radial Basis Functions) methods. On the other hand, in approximate or geostatistic methods the interpolated surface might not pass through the sampling points; similar to Kriging method. In other words, in approximate or geostatic methods some degrees of uncertainty are taken into account while estimating the amounts of unknown points (Iran ministry of energy, 2010).

2.3 Cross validation

There are various methods for validation of interpolation methods. One of these methods is cross validation. In his method, one of the known points is eliminated temporarily and this eliminated point is estimated by the amounts of other known points. Then the eliminated point is returned and another point is eliminated. In this way, the estimation is conducted for all of the points. Finally, the estimated amounts are compared with the sampled amounts and the most precise interpolation method is determined (Davis, 1987). There are a number of methods to compare the estimated amounts with the sampled amounts. One of these methods is RMSE (1).

$$RMSE = \left(\frac{SSE}{n}\right)^{1/2} \tag{1}$$

RMSE: Root Mean Square Error
SSE: Sum of Squares Error
n: The number of sampled points

In the mentioned equation, by lowering the error of estimation, higher precision could be attained in predictions by the interpolation methods.

2.4 Results of cross validation

In this study various method such as IDW, RBF (completely regularize spline, spline with tension, multiquadric, inverse multiquadric, thin plate spline) and simple kriging (spherical, circular, exponential, Gaussian) are evaluated through cross validation. Next, the methods that predicted the insolation with less error are verified by applying RMSE. The results reveal that RBF predict the amounts of monthly, seasonal and annual insolation with higher precision (Table 2).

Table 2 The results of validation of interpolation methods using the RMSE

Time	Inverse Distance Weighting	Radial Basis Functions					Simple kriging			
		Completely regularize spline	Spline with tension	Multiquadric	Inverse multiquadric	Thin plate spline	Spherical	Circular	Exponential	Gaussian
January	.106	.094	**.093**	**.093**	.094	**.093**	.1	.1	.1	.103
February	.142	.125	**.123**	.124	.124	.124	.134	.134	.135	.139
March	.151	.134	**.133**	**.133**	.134	.134	.143	.143	.143	.15
April	.154	.131	.13	**.128**	.13	.13	.143	.143	.144	.152
May	.183	.161	**.155**	.156	.161	**.155**	.177	.178	.168	.184
June	.22	.205	.202	.202	.206	**.201**	.22	.22	.215	.218
July	.214	.191	.182	.184	.191	**.181**	.21	.211	.206	.209
August	.193	.166	.162	**.16**	.165	.162	.184	.185	.18	.186
September	.182	.155	.155	**.154**	.155	.157	.176	.177	.168	.18
October	.126	**.111**	**.111**	.112	**.111**	.116	.117	.117	.118	.121
November	.093	**.076**	**.076**	**.076**	**.076**	.08	.082	.083	.083	.085
December	.088	.074	**.073**	**.073**	.074	**.073**	.077	.077	.078	.08
Spring	.175	.155	**.15**	**.15**	.154	**.15**	.171	.172	.161	.176
Summer	.19	.164	**.159**	**.159**	.163	.16	.183	.183	.179	.185
Autumn	.092	**.077**	**.077**	**.077**	**.077**	.079	.082	.082	.083	.084
Winter	.128	.112	**.11**	.111	.111	.111	.12	.12	.121	.126
Annual	.128	.106	.105	**.103**	.105	.105	.115	.115	.116	.125

2.5 Coefficient of variation

The coefficient of variation for annual insolation is analyzed spatially in this study. The coefficient of variation indicates the level of change and variation for the features of a given population (2).

$$CV = \frac{\sigma}{\mu} \times 100 \tag{2}$$

CV: Coefficient of variation
σ: Standard deviation
μ: Population mean

3. Findings and results

As the findings reveal, the lowest amount of radiation is received in December. The average radiation in this month varies from 1.6 to 3.8 kWh/m^2/day (kilowatt hour per square meter per day) (Fig.3). In this month, the westerlies and Mediterranean high trough, the climate systems that control weather in cold seasons in Iran, would lead to baroclinic atmosphere (an instable atmosphere with vertical motions) (Alijani, 2010). The instability of weather and cloudiness also result in the reduction of insolation. Short day length is another factor which plays a role in low levels of insolation. In December, the north, the northwest, and parts of northeast of Iran receive the lowest levels of radiation with the average that varies between 1.6 and 2 kWh/m^2/day. The reason is higher latitude that leads to a more inclined solar angle and hence a lower radiation intensity. The cloudiness, less hours of daylight, and shorter day length are among the other effective factors in low levels of insolation in these regions (Table 3). The south and southeast of Iran receive the highest levels of radiation with the average ranging between 3.5 to 3.8 kWh/m^2/day. The reason for this phenomenon is lower latitude which results in more vertical solar angel and hence receiving higher levels of insolation. Other determining factors include lower cloudiness, more hours of daylight, and longer day length (Table 4).

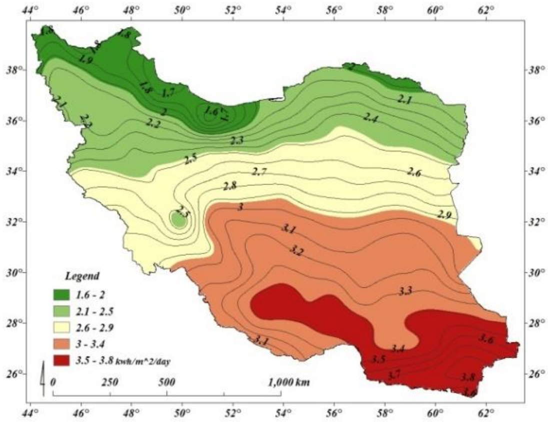


Fig.3 The insolation in December (kWh/m^2/day)

Table 3 The average of effective variables in insolation levels for north, northwest, and parts of northeast of Iran in December (1983-2005)

Northern latitude (degree)	Eastern longitude (degree)	Solar angle (degree)	Day length (hour)	Sunshine hours	Cloudy days
36	51	31.1	9.8	4.9	9.4
37	49	30.1	9.7	4.4	9.4
38	48	29.1	9.6	4.4	8.4
39	45	28.1	9.5	3.9	10.1

Table 4 The average of effective variables in insolation levels for south and southwest of Iran in December (1983-2005)

Northern latitude (degree)	Eastern longitude (degree)	Solar angle (degree)	Day length (hour)	Sunshine hours	Cloudy days
25	61	42.1	10.6	8.2	1.4
26	60	41.1	10.5	8	1.5
27	61	40.1	10.4	7.9	2.3
28	57	39.1	10.4	7.5	2.6
29	56	38.1	10.3	7.3	3.3

The highest level of insolation is received in June. The average insolation in this month ranges between 5.7 to 7.8 kWh/m^2/day (Fig.4). In this month, Subtropical Jet Stream (SJS) and Subtropical High Pressure (STHP), the climate systems that control Iran's weather in warm seasons, would cause barotropic atmosphere (stable atmosphere with no vertical motion) (Alijani, 2010). The stability of the climate and the clear sky also intensify the insolation. Long day length could be considered as another factor contributing to high levels of insolation in this month. In June, the southwest, west, and parts of northwest in Iran receive the highest levels of insolation with the average ranging from 7.5 to 7.8 kWh/m^2/day. This is due to the long day length and high clear sky insolation (insolation in the sky with less than 10 percent of cloud) (Fig.5). High levels of insolation in clear sky in east and parts of northeast are due to the height from the sea level (Fig.6). In higher regions, the atmospheric composition is thinner and the thickness of atmosphere is low, therefore more insolation is received by the earth (Alijani, 2010). Some parts of north of Iran with the average ranging from 5.7 to 6.1 kwh/m^2/day receive the least insolation. High levels of cloudiness highly affect the insolation received in this region.

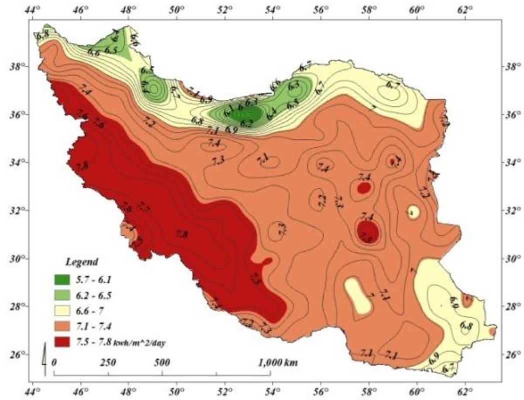


Fig.4 The insolation in June (kWh/m^2/day)

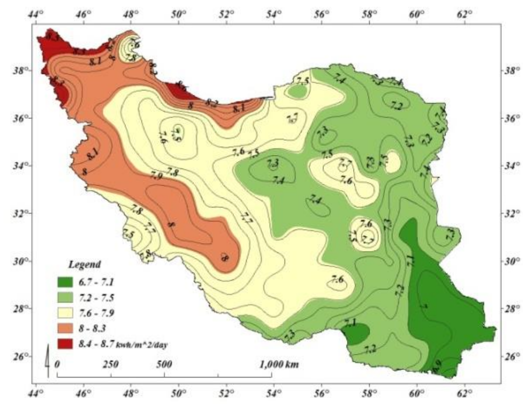


Fig.5 The clear sky insolation in June (kWh/m^2/day)

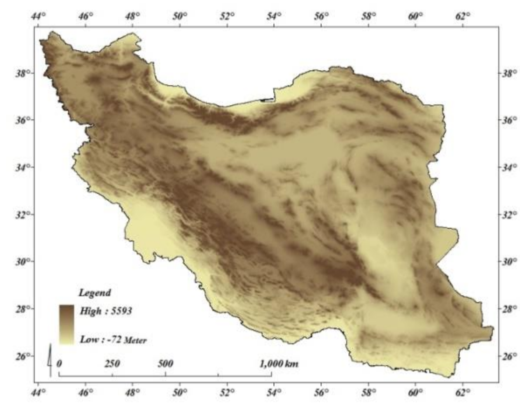
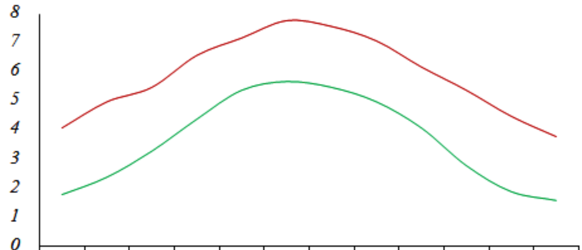


Fig.6 Iran topography (meter)

The average insolation from January to June shows an ascending progress and from June to December it shows a declining trend (Fig.7).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	4.1	5	5.5	6.6	7.2	7.8	7.6	7.1	6.2	5.4	4.5	3.8
Min	1.8	2.4	3.3	4.4	5.4	5.7	5.5	5	4.1	2.8	1.9	1.6

Fig.7 The monthly minimum and maximum insolation (kWh/m^2/day)

The minimum insolation is variable in different months of the year in north, northwest, and northeast and the maximum insolation is variable in southeast, south, west, and the center of Iran.

In cold seasons, autumn and winter, the least insolation is received. Total insolation in these seasons varies from 6.3 to 13.7 and 7.4 to 14.7 kWh/m^2/day, respectively. The north and parts of northwest of Iran receive the lowest levels of insolation and, on the other hand, southeast and parts of south and the center receive the highest levels of insolation.

In warm seasons, spring and summer, the most insolation is received. The total insolation in these seasons varies from 15.9 to 21 and 14.5 to 20.8 kWh/m^2/day, respectively. Some parts of north and northwest receive the lowest levels of insolation and south, southeast, west, and the center of Iran receive the highest levels of insolation.

The total annual insolation ranges from 45.7 to 68.2 kWh/m^2/day. Some parts of north and northwest of Iran receive the lowest levels of insolation with a record of 45.7 to 50.2 kWh/m^2/day, and south, southeast, and the center of Iran receive the highest levels of insolation with a record of 63.8 to 68.2 kWh/m^2/day (Fig.8).

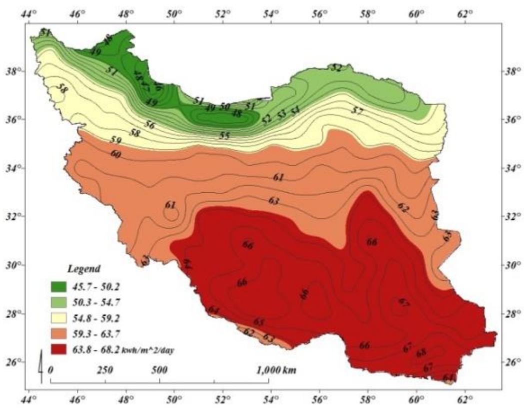


Fig.8 The annual insolation (kWh/m^2/day)

The coefficient of variation for annual insolation ranges from 19 to 46.9 percent. The southeast and parts of south show the lowest coefficient with a record of 19 to 24.6 percent. And the north and parts of northwest of Iran show the highest levels of insolation with a record of 41.4 to 46.9 percent (Fig.9).

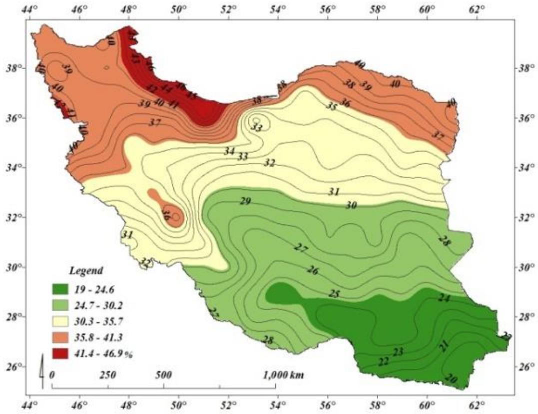


Fig.9 The coefficient of variation for annual insolation (%)

4. Discussion and conclusion

This study offers a spatial analysis of insolation in Iran region. The results of this study could be applicable and important. There are some reasons that contribute to the significance of this study: using the insolation data instead of other climate parameters, long statistical period without dubious data, the numbers and positions of sampled points, employing precise interpolation methods for spatial analysis of monthly, seasonal, and annual insolation.

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