Wind Speed Estimation for Iraq using several Spatial Interpolation Methods

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Abstract

To decide the best method of interpolation for estimating the wind speed in Iraq region, five spatial interpolation techniques are tested (i.e. inverse distance weighted, global polynomial interpolation, local polynomial interpolation, spline with 3 sub-types, and kriging with 4 sub-types) and evaluated. Based on the root mean square error values, the predicted values are compared for period between 1971 and 2010. The results showed that the inverse distance weighted IDW yielded the best results, while the ordinary Kriging method occupied the ranked second.

Keywords: wind speed, spatial interpolation, GIS

1. Introduction

Renewable energy is a well-established technology, and a domestic resource that has the potential to supply power to the whole world. It is becoming increasingly evident that renewable energy technologies have a strategic role to play in the achievement of the goals of sustained economic development and environmental protection **[1,2]**.

Windmill is one of the renewable energy technologies which can convert the potential in winds to electricity. Now it is widely seen as important if the world is to move toward a sustainable approach to energy generation. However, there are ranges of obstacles facing the rapid development of these technologies: they are trying to establish themselves in an outdated institutional, market, and industrial context **[3]**.

Windmills establishment needs many investigations before starting the operations of erecting them. The most important factor to consider in the construction of a wind energy facility is the site's wind resource. A site must have a minimum annual average wind speed in the neighborhood of 11-13 mph to be considered. Local weather data available from meteorological stations may provide some insight as to averages. How far is the windmills farm from existing transmission lines is a critical issue in keeping costs down in building a wind farm. Landowners, both private and public should be taken in consideration (expecting their demands for compensation). Taking advantage of economies of scale; i.e. wind power facilities should be in excess of 20 MW. Also, reliable power purchaser or market should be identified.

2. Spatial Interpolation Methods:

A very basic problem in spatial analysis is interpolating a spatially continuous variable from point samples. Five most commonly used interpolation methods to model spatially distribution from point data have been chosen to be investigated and compared in this study, these are:

2.1 Global polynomial interpolation:

Global methods utilize all the known values to estimate an unknown value, while in local methods only a specified number of nearest neighbors are used to assess an unknown value. Global polynomial interpolation does not use local information, it fits a polynomial regression to the surface **[4]**. Degree of polynomial describes the difficulty of the physical meaning (i.e. the more complicated the polynomial, the more difficult it is to assign physical meaning to it). A first-order global polynomial fits a single plane through the data; a second-order fits a surface with a bend in it, allowing the calculation of surfaces representing valleys; a third-order allows for 2 bends; and so forth.

2.1 Local polynomial interpolation:

The local polynomial interpolation creates a surface from many different formulas, each of which is optimized for a neighborhood. The neighborhood shape, maximum and minimum number of points and sector configuration can be specified. The neighborhood can be weighted by their distance from the predicted location, therefore, local polynomial interpolation produces surfaces that better account for local variation. The polynomial is fitted to a local subset defined by a window which is a circle as the simplest moving window with radius *R*. If the distance between grid point (x_i ,y_i) and a data point (x ,y) within the circle is denoted d_i, then the weight w_i is defined as:

$$w_i = (1 - \frac{d_i}{R})^p \tag{1}$$

Where, *p* is a user definable power **[5]**.

2.3 Inverse distance weighted interpolation:

Inverse Distance Weighted (IDW) interpolation implements a basic law of geography; i.e. things that are close to one another are more alike than things that are far apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. Notice that as the distance approaches zero, the relative weight approaches one.

This method basically depends on estimating the height of the unknown points "Z(x, y)" by computing the distances from this point to the other known points, as it mathematically clarified by the following, **[6]**.

$$Z(x,y) = \frac{\sum_{i=1}^{n} [\frac{Z_i}{d_i^p}]}{\sum_{i=1}^{n} [\frac{1}{d_i^p}]} \tag{2}$$

$$Z(x,y) = \sum \lambda_i \times Z_i \xrightarrow{where} \sum \lambda_i = 1 \tag{3}$$

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} \tag{4}$$

Where: "*Z(x ,y)*" is the predicted value at the ensample location *x ,y*, "*i*" is the number of measured sample points within the neighborhood defined, "Z_i" is the observed value at location *"i"*, d_i is the distance between the predicted location x, y and the measured location *"i"* , λ_i is the distance-dependent weight associated with each sample point; and *"p"* is the power parameter that defines the rate of reduction of the weight as distance increases.

2.4 Kriging interpolation:

The Kriging assigns weights according to a data-driven weighting function, rather than an arbitrary function, but it is still just an interpolation algorithm and gives very similar results to others in many cases. In particular: regardless of the used interpolation algorithm, fairly good estimates can be obtained if the data locations are fairly dense and uniformly distributed, also, if the data locations fall in a few clusters with large gaps in between. Moreover, underestimation of highs and overestimation of the lows are normally obtained if an interpolation algorithm didn't include averaging process.

In Kriging, the trend part of a prediction is called the trend, while the fluctuation part is called spatially-autocorrelated random error. Four different kriging types have been used in this study; i.e. [7]

a. *Simple kriging*: *Mathematically it is the simplest, but the least general. It assumes the expectation of the random field to be known, and relies on a covariance function. However, in most applications neither the expectation nor the covariance are known previously.* Practically, the simple kriging assumptions are;
   - *Wide sense stationary of the field.*
   - The expectation is zero everywhere ($\mu(x)=0$ *); where:* $\mu(x)=\{Z\}$
   - *Known covariance function; i.e.* $c(x,y)=Cov(Z(x),Z(y))$

b. *Ordinary kriging*: assumes an unknown constant trend: μ(x) = μ.

c. *Universal kriging*: assumes a general polynomial trend model, such as linear trend model.

d. *Disjunctive kriging:* is a nonlinear generalization of kriging.

2.5 Spline interpolation: A spline is a polynomial between each pair of table points, but one whose coefficients are determined "slightly" non-locally. The non-locality is designed to guarantee global smoothness in the interpolated function up to some order of derivative **[8]**. Spline method produces a continuous surface with minimum curvature. Radial Basis function (RBF) [***which is a real-valued function whose value depends only on the distance from the origin or from some other point***] methods such as Spline are exact interpolation techniques; the surface is forced through each measured sample value. RBFs include thin-plate spline, spline with tension. The selected basic function determines how the rubber membrane will fit between the values. As opposed to IDW, RBF methods can predict values above the maximum and below the minimum measured values.

3. The Studied Area

Iraq lies between latitudes 29° and 38° N, and longitudes 39° and 49° E (*the top-bottom photomap geo-coordinates are 37°22′17″N, 38°48′33″E, while the right at 29°06′10″N, 48°36′15″E*). Spanning 438,317 km^2, it is the 58th largest country in the world, shown in figure-1

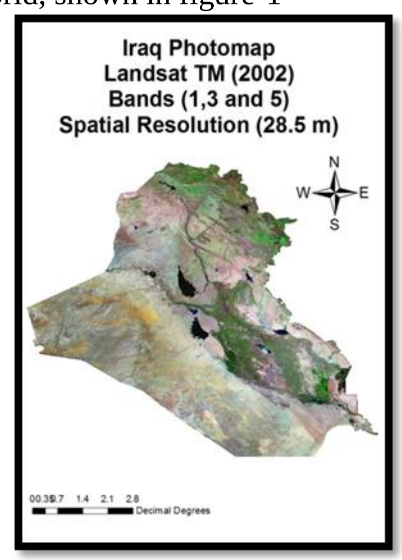


Figure-1: Iraq Country Photomap.

4. Methodology

Preparing the photomap for the studied region (fig.-1), was done by utilizing the Landsat Enhanced Thematic Mapper ETM_+ bands (1,3, and 5) of spatial resolution (28.5m), using ArcMap software. The administrative border of the provinces has been based on Google Earth and other reference maps. Establishing shape files (point, line and polygon) were performed by ArcCatalog software. The geographic coordinate system (WGS_{84}) corroborated by the ArcGIS software.

The location of the invested metrological stations are shown in figure-2 below.

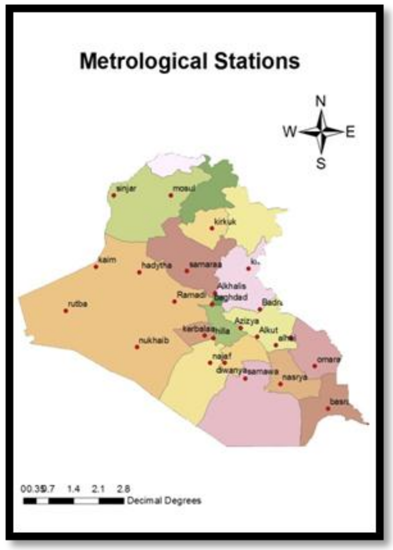


Figure-2: Photomap illustrating the locations of the invested Metrological stations.

The wind speed data that was collected from the Iraqi's metrological stations has been prepared in a suitable format to be manipulated by the ArcGIS software. The provided data was prepared in monthly format mean data, so it was easy to transfer them into annual mean, as illustrated in figure-3.

In order to cover all points of study area, the available interpolation methods in the ArcGIS have been utilized (i.e. IDW, Global, Local, Spline, Kriging, and Radial Basis Function).

All these methods were used and calculated using GIS facilities and the root mean square error (RMSE) was created. In the GIS environmental, The Geostatistical analysis tool had been used to overcome the results. This technique needs a calculation that were overcome by IDW, Spline, etc. The advantage of using that calculation was to extract the output map with new data editing and reconstruction.

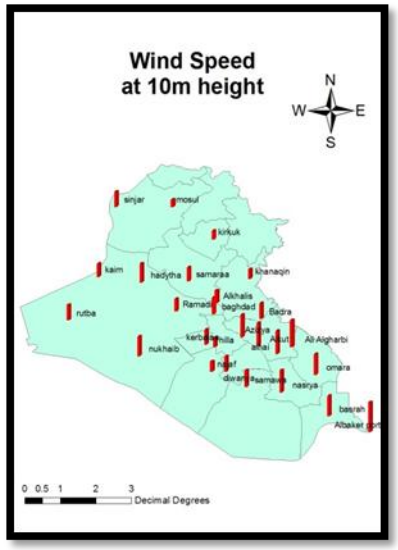
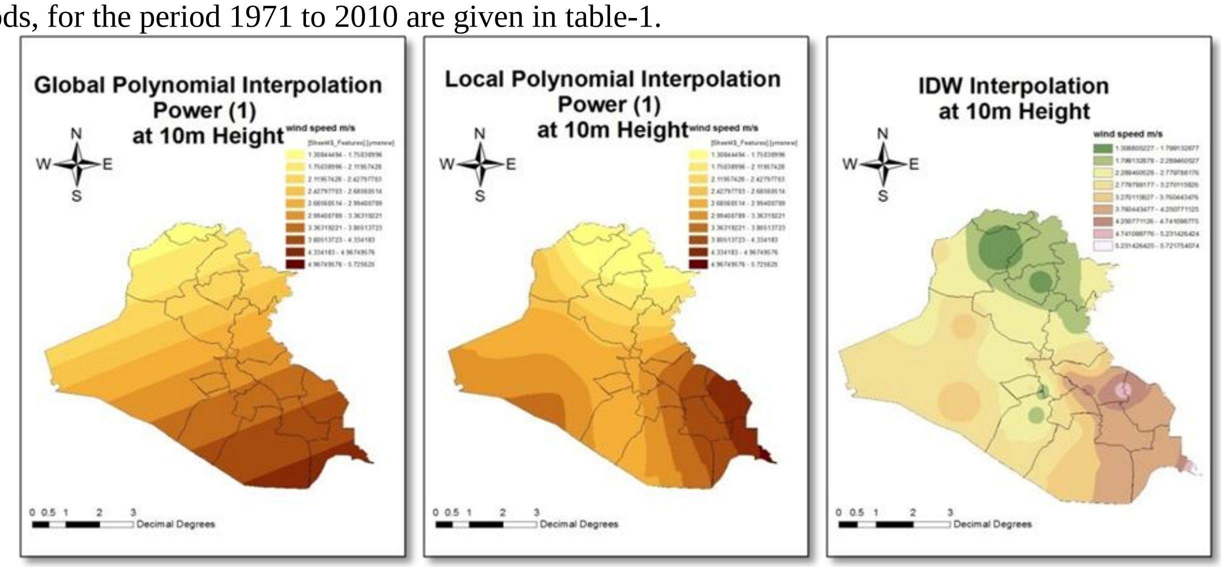


Figure-3: Annual wind speed map at 10m height.

The calculated error was in real equal to the actual minus predicted and the mean of these errors was calculated in 2 ways. Where, the mean error (ME), indicating the degree of bias; root mean square error (RMSE), providing a measure that is sensitive to outliers. (RMSE) values has the same units as the quantity being estimated representing an unbiased estimator (the square root of the variance), known as the standard deviation.

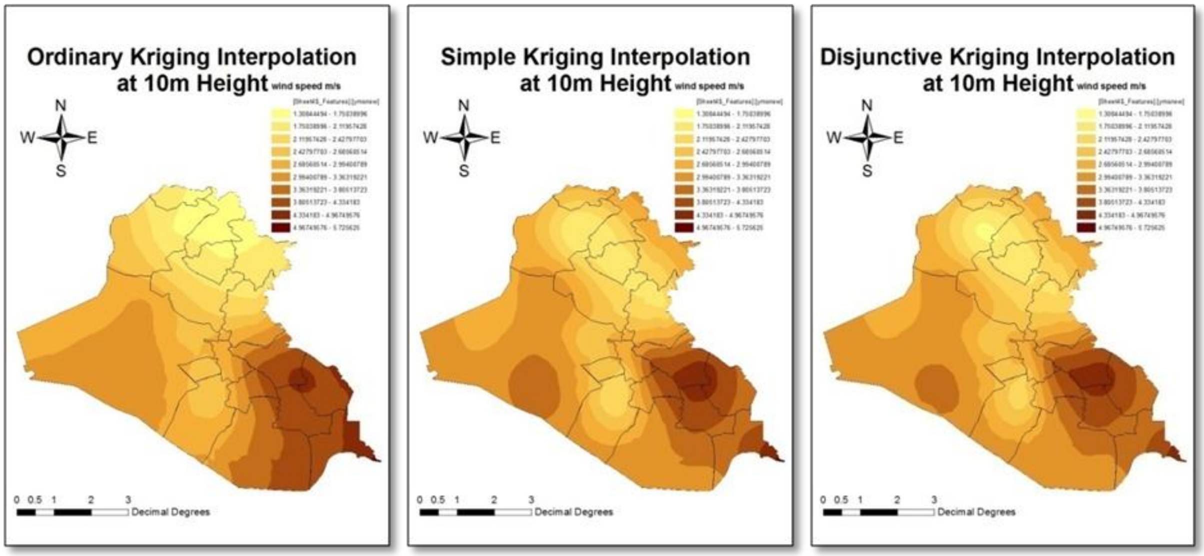
5. Results and discussions

The annual prediction maps which have been generated for wind speeds, using the mentioned interpolations are shown in figs.4-5. The statistical details of the errors produced by the adopted interpolation methods, for the period 1971 to 2010 are given in table-1.



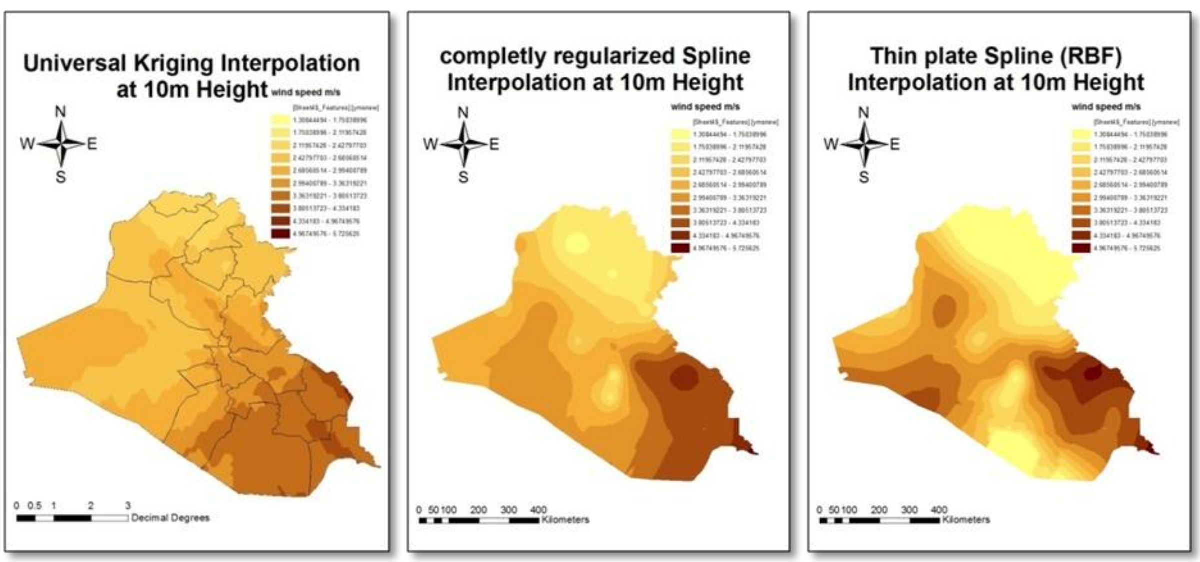
a

b c



d **e** **f**

Figure-4: Predicted wind speeds using: a) Global Polynomial Interpolation, b) Local Polynomial Interpolation, c) Inverse Distance Weight, d) Ordinary Kriging Interpolation, e)Simple Kriging Interpolation, and f) Disjunctive Kriging Interpolation.



a **b** **c**

Figure-5: Predicted wind speeds over Iraq, using: a) Universal Kriging Interpolation, b)B-Spline Interpolation, and c) Thin Plate Spline (RBF).

Table-1: Statistical errors obtained by the used interpolation methods for period 1971–2010

Interpolation method	Number of points	Mean Error (ME)	Root Mean Square Error (RMSE)
IDW	26	-0.04335	0.8029
Local poly	26	-0.06728	0.8372
Global poly	26	-0.01507	0.9392
Ordinary Kriging	26	-0.03542	0.8113
Simple Kriging	26	0.02439	0.8665
Universal kriging	26	-0.1261	0.9416
Disjunctive Kriging	26	0.02935	0.8591
spline completely regularized	26	-0.05101	0.8146
spline with tension (RBF)	26	-0.05039	0.8159
spline with thin plate (RBF)	26	-0.03977	0.9616

As it is obvious, the global polynomial interpolation produced the worse results (i.e. highest RMSE), it may be unsuitable for slowly varying surfaces. However, the local polynomial interpolation can't also be recommended because it produced poor results (i.e. the RMSE by this method is better than the global polynomial interpolation but still unacceptable). The IDW yields lowest RMSE values, it is recommended by Dirks et al. (1998) **[9]** for rainfall interpolation. The advantages gained from using IDW is; because it is appropriate for the measured range of the data, see Johnston et al. (2001) **[10]**.

The completely regularized spline method produced good RMSE values (it is suitable for large number of data points and varying surfaces), it is appropriated to be used with climate data. The ordinary Kriging method produced almost minimum RMSE values, especially when applied to wind speed, while the simple and disjunctive Kriging methods were not. In fact, subtypes of kriging generally gave roughly similar results.

6. Conclusions

This study aimed to determine the best method interpolation method for the spatial distribution of wind speed over Iraq region for the period 1971 to 2010. Based on the ME and RMSE prediction values, the IDW interpolation is proved successfulness over other adopted interpolation methods. The second recommended method that can be used is ordinary Kriging interpolation which gave reasonable results.

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