

COMPARISON OF EXTREME WIND DRIVEN RAIN EXPOSURE MAP OF INDIA BY INVERSE DISTANCE WEIGHTED METHOD(IDW) AND KRINGING INTERPOLATION METHOD

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Abstract: *Wind Driven Rain (WDR) is referred to as the most important source of moisture intrusion in the vertical building facades. It has been a major source of concern from the durability aspects of a building as adequate information about it is required for a good hygrothermal performance of a building. Rain with simultaneous occurrence of wind gives rise to an oblique intensity rain vector which is referred to as WDR. The exposure of the facades of a building to WDR is significantly important to calculate the wet load and adopt suitable measures to protect the building. The WDR distribution on the vertical building façade depends on wind speed and rainfall intensity. It is also affected by climatic conditions as per geographical location, components of building and materials used for construction of wall surface. India is a large country with complex geographical features and varied climates in various regions. Hence to promote the construction of sustainable building construction and facilitate the renovation of existing buildings in India, it is necessary to calculate the amount of WDR in various regions of India to draw WDR map of India. In this paper WDR map using data of 61 years (1951-2010) has been used to calculate the Driving Rain Index (DRI) values. Then by using the Inverse Distance Weighted (IDW) method and Kriging method of ArcGIS the WDR map is prepared and then comparison has been done. It is found that the Kriging method of interpolation to prepare WDR map gives more accurate results.*

Keywords: *Inverse Distance Weighted, Kriging, Wind Driven Rain.*

1. INTRODUCTION

Rain with simultaneous occurrence of wind gives rise to an oblique intensity rain vector which is referred to as Wind Driven Rain (WDR) and it is a major source of concern from the durability aspects of a building as adequate information about it is required for a good hygrothermal performance of a building [1]. WDR measurements are done by rain gauges consisting of a shallow collection of trays, drainage tubing and a collection reservoir. It has a raised rim to facilitate proper collection of the rain water. The amount of rain water collected is measured at regular intervals in terms of volume or weight. There is no standard gauge which is industrially manufactured to measure Wind Driven Rain [1]. However, the shape, size and the material used is different for different types of gauges. The exposure of the facades of a building to WDR is significantly important to calculate the wet load and adopt suitable measures to protect the building. The WDR distribution on the vertical building façade depends on wind speed and rainfall intensity [1].

It is also affected by climatic conditions as per geographical location, components of building and materials used for construction of wall surface. Several field observations, numerical simulations and semi-empirical methods were adopted by researchers' time to time to find out accurate measurements of WDR on the vertical facades of buildings. Experimental methods are very much reliable however uncertainty of measuring instrument, unfavourable climatic conditions, and prolonged time consumption act as limitations [14]. Detailed WDR distribution of raindrops pattern on the walls of the building can be obtained by numerical simulations but it is time consuming as well as requirement of layout information in details are required for calculation. However, calculations through semi-empirical methods are easier, less time consuming and widely relates to practical engineering applications. Researchers have derived various semi-empirical formulas such as Driving Rain Index (DRI) to calculate WDR exposure of a building facade [15]. The DRI when calculated annually, it is known as aDRI. The DRI when calculated on daily basis, monthly basis on average and annual meteorological data, they are known as daDRI , mDRI respectively[15]. According to daDRI calculated values Lacy and Shellard classified WDR into shield, moderate, high, and severe [15].

Researchers have worked on drawing WDR map for various countries like Greece [17,18], Brazil [16], China [14] and India [6,8]. For India maps were drawn for $1^{\circ} \times 1^{\circ}$ latitude & longitude. India is a vast country with climatic variations in various regions. The aDRI calculated is different for data noted down for different time resolution and meteorological data for different time resolutions due to variations in climatic conditions [19]. The differences in such calculations arises mainly because data noted down for low time resolution omits the simultaneous occurrence of wind and rain. Therefore, data with low time resolutions considers the wind speed which is not accompanied by rainfall. Therefore, data noted with high time resolution gives more accuracy in results for calculating WDR loads. Thus, hourly, and daily datasets give more accuracy than monthly and annual datasets [19].

Apart from these, ISO Semi empirical calculations [20] are also there to estimate quantitatively the WDR exposure of a single rainfall event which requires wind direction data. Calculations for WDR exposure about a particular direction is done based on hourly weather data, thus giving more comprehensive and realistic results. Hourly rainfall data for long duration is not available for many places. Hence for calculation in such cases without the availability of wind direction data has been proposed by researchers. One such parameter is Absolute Spell Index (I_{AS}) which calculates on the climate data recorded on daily basis [20]. The orientation of the wall facade when ignored during the rainfall event, it helps in extending the time period regardless of wind direction and absolute spell indicates no precipitation in the site for 96 consecutive hours before and after the rainfall event in the site. I_{AS} is the measure of the amount of WDR during the rainfall event at the given site.

India is a large country with complex geographical features and varied climates in various regions. Hence to promote the construction of sustainable building and facilitate the renovation of existing buildings in India, it is necessary to calculate the amount of WDR amount in various regions of India to draw WDR map of India. WDR map of India has been drawn by Narula et al [2018] by Kriging method. In this paper WDR map using data of 61 years (1951-2010) has been drawn using the Inverse Distance Weighted (IDW) method and Kriging method of ArcGIS 10.4.1 to calculate the extreme wind driven rain exposure map of India and comparison has been drawn between the two methods.

1.1 Methods Of Interpolation

The methods of interpolation are geostatistical and deterministic methods. Inverse Distance Weighted Method (IDW) is deterministic method which creates surfaces from points having measured values. Kriging Method is geostatistical method which involves statistical properties of measured points for interpolation.

1.1.1 Inverse Distance Weighted Interpolation Method

The Inverse Distance Weighted (IDW) method is the most used technique of interpolation which is based on the fundamental assumption that the interpolating surface is mostly influenced by the nearby points than that by distant points. The weighted average of the scatter points is the interpolated surface and with the increase in the distance between the interpolation point and the scatter point, the assigned weights of each scatter point decrease. The unknown point values are obtained by calculation from the weighted average of the values of the known points [11].

The basis of interpolation in this method uses the influence of one point relative to other decreases with the increase in distance.

The formula of IDW method used-

$$Z(Y_0) = \sum_{i=1}^N U$$

$$U = Z(Y_i) \lambda_i$$

N = No. of observation points scattered in the dataset

$Z(Y_i)$ = scattered observation points values $i=1, 2, \dots, N$

λ = values assigned to observation points

$$\lambda_i = \frac{R}{P}$$

$$R = d_{ij}^{-p}$$

$$P = \sum_{i=1}^N R$$

p = power of the weights assigned to points

d_{ij} = Inbetween distance of grid node i and neighbourhood point j

The surface produced becomes polygonal due to the increase in the power.

1.1.2 Kriging Interpolation Method

The Kriging method is mostly used for interpolation in Geostatistics and is proved to be huge enough to estimate the values of unsampled locations based on the sampled data [12]. It is comprised of a group of geostatistical methods used for interpolating the different regional variables' values at the locations which are unobserved from the values observed in the nearby locations consisting of Ordinary Kriging, Universal Kriging, Indicator Kriging, Co-Kriging and others [13]. Ordinary Kriging method of interpolation is one of the Kriging method which is very important for interpolation and data mapping. Ordinary Kriging is the most commonly used, most popular and most efficient interpolation method and plays a very significant role as it is compatible with a stationary model and only utilizes the variogram. In this paper Ordinary Kriging was used.

In this method a spatial correlation is reflected by the distance or direction between the sample points to explain surface variation. Here a mathematical function is used within a specified radius to fit a specific number of points to determine the value of new point.

The formula used for Kringing method is-

$$Z(Y_0) = \sum_{i=1}^N \lambda_i \cdot Z(Y_i)$$

$Z(Y_0)$ = point of interpolation

N = scattered observation points in the given dataset

$Z(Y_i)$ = scattered observation point values

λ_i = weights assigned by using model variogram instead of using them as function of distance.

2. METHODOLOGY

The following steps are followed :

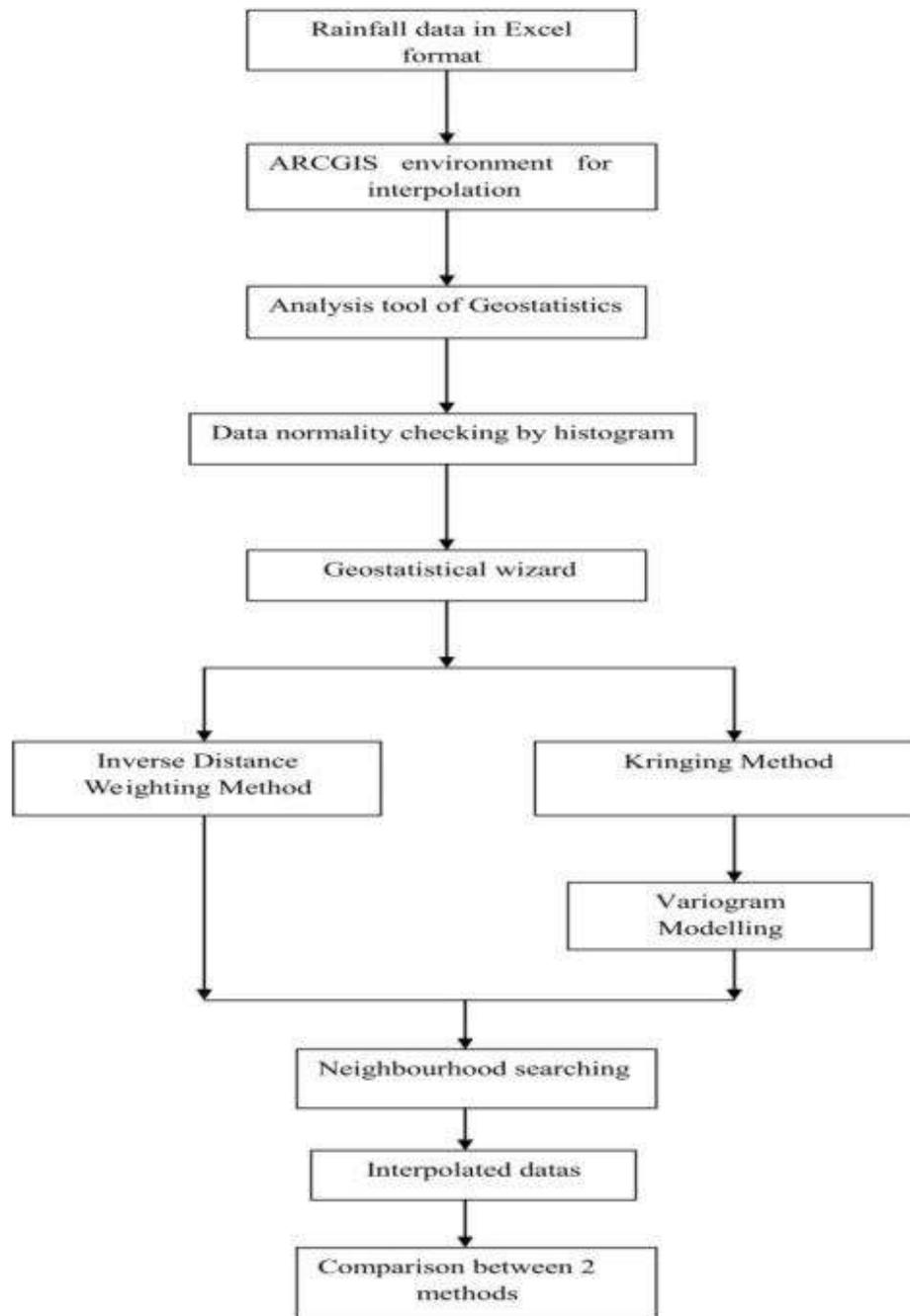
- Rainfall data along with wind speed from 1951 to 2010 is collected from the archives of India Meteorological Department.
- The Daily Driving Rain Index (daDRI) is calculated by using the following formula:

$$daDRI = \frac{1}{n} \times \sum_{i=1}^k \frac{1}{1000} (h_i^d \times u_i^d)$$

where, n = no. of years = 61, k = daDRI calculation on daily meteorological data in comparison with monthly and annual meteorological data gives better analysis of WDR exposure.

- Base map of India is to be prepared by using Inverse Distance Weighted Method (IDW)[Fig.2] by using ARCGIS 10.4.1. It is compared with base map of India prepared by Narula et al(2018)[Fig.1] by Kringing Method .
- Normal data distribution is ensured by checking statistical properties.
- Determination of variogram of the recorded data.
- Plotting of experimental variogram by using computed variogram.
- Fitting of the best variogram model through experimental variogram.
- Spatial autocorrelation between sample point is checked by using this model.
- A search radius is specified.
- Then points are interpolated using the Inverse Distance Weighted Method.

The flowchart of the work:



3. RESULTS

The maps obtained from the two different methods of interpolation shows that the daDRI values for each state is very clearly justified in Kriging Interpolation [Fig.1] than that shown by Inverse Distance Weighted Method [Fig.2].

Certain standards of estimates are used to cross validate the various effects of interpolation. In cross validation Mean Error (ME), Mean Standard Error (MSE), Average Standard Error (ASE), Root Mean Square Error (RMSE), Root Mean Square Standard Error (RMSSE) are used for evaluation of effectiveness of interpolation methods. The comprehensive standards of comparison are as follows: ME nearing to 0, MSE nearing to 0, smallest value of RMSE, ASE nearest RMSE, RMSSE nearing to 1. The comparison of prediction errors is given in Table 1.

Table 1 Comparison of prediction errors

METHODS	ME	MSE	ASE	RMSE	RMSSE
IDW METHOD	-5.301	9.499	74.66	161.84	10.245
KRINGING METHOD	-4.856	-0.029	163.26	161.29	0.985

On analysis of the prediction error MSE, ASE and RMSSE, great differences are observed. The MSE value is approximately 0. The value is far exceeded by IDW. Kriging method is very close to 0. The best result for RMSSE is near to 1 whereas for IDW method it is 10.36 and for Kriging method it is close to 1. ASE value should be close to RMSE for IDW but for ASE it is far away from RMSE. Therefore, by analysis of interpolation errors, it is observed that interpolation by Kriging method surpasses IDW method.

We see that the contour of IDW method [Fig. 3] is denser than Kriging method [Fig. 4]. On comparing the contours, we see that the Kriging method can depict the changing trend of daDRI values in the whole region very well whereas detailed local changes cannot be represented well. For IDW method, interpolation precision is less but depiction of detailed changes locally is good than that of Kriging method.

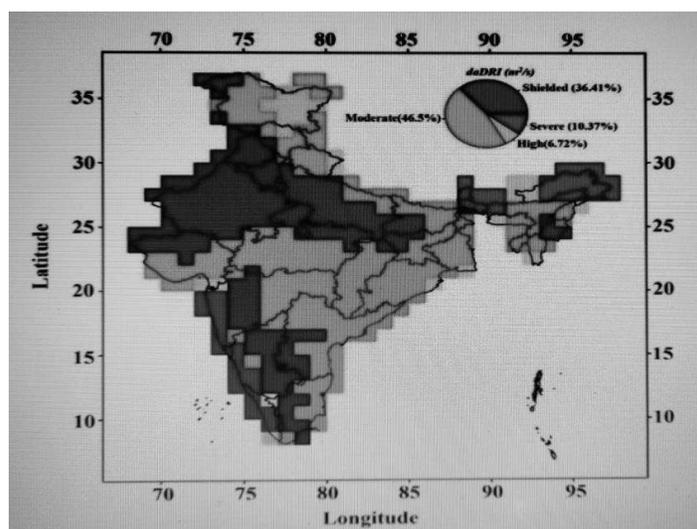


Figure 1: Interpolation by Kriging Method [Narula et al., 2018]

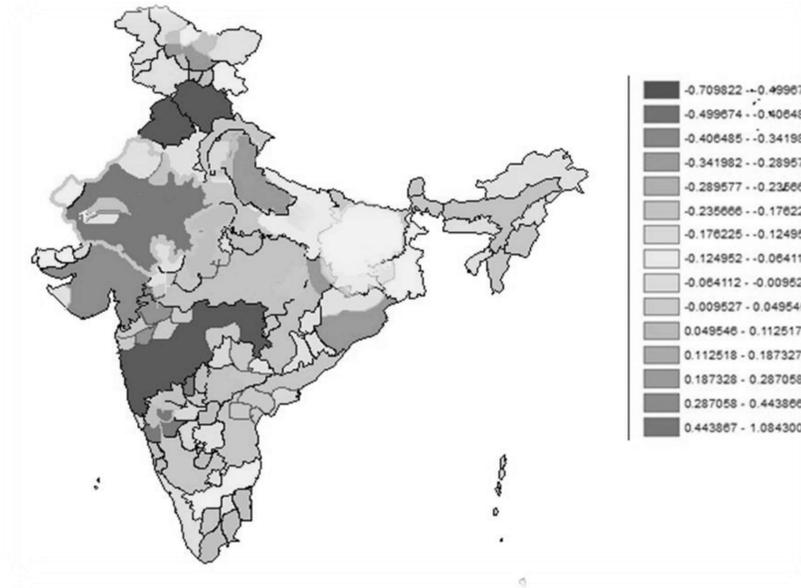


Figure 2: Interpolation by Inverse Distance Weighted Method

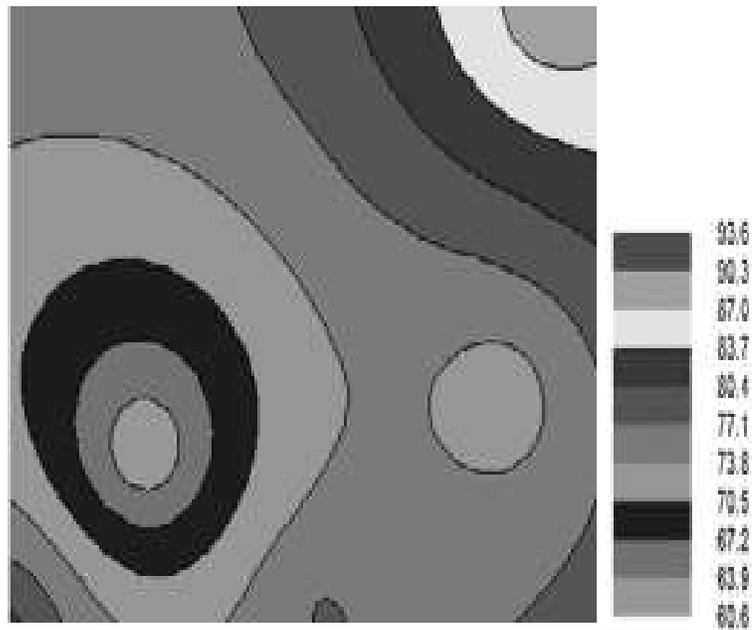


Figure 3: IDW contour

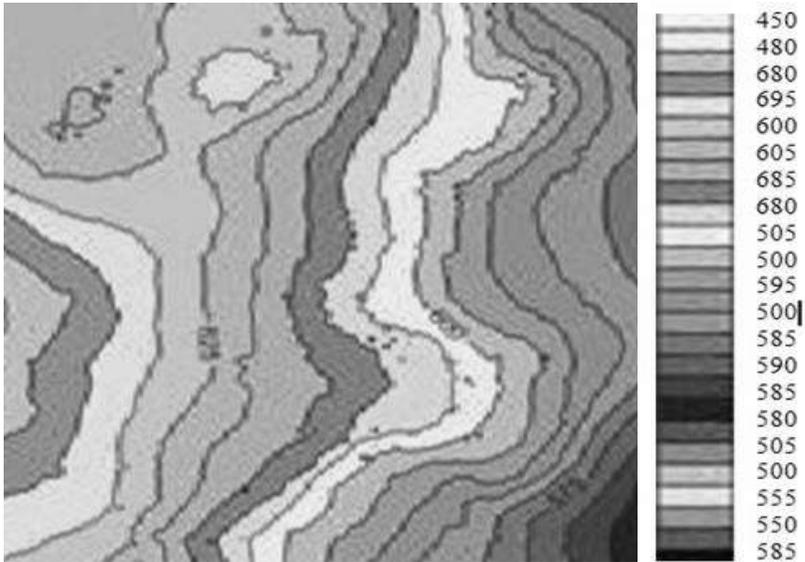


Figure 4: Kriging contour

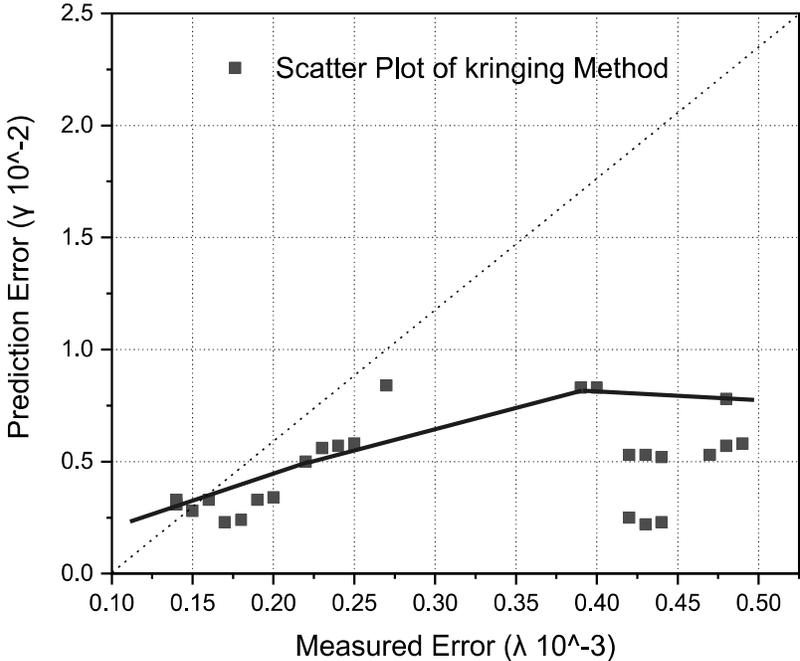


Figure 5: Scatter Plot of measured vs predicted error in Kriging Interpolation Method (All dimensions are in mm)

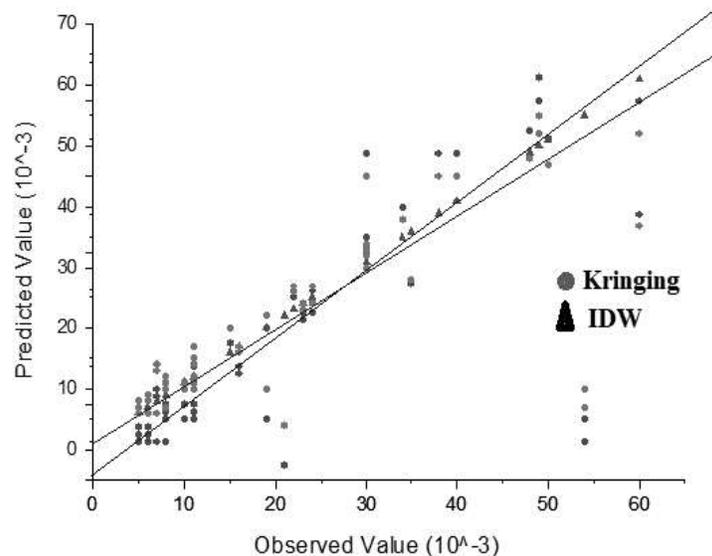


Figure 6: Comparison between the scatter plot of observed values in Kriging and IDW Interpolation Method (All dimensions are in mm)

4. CONCLUSION

From the various analytical results, we arrive at the following conclusions: (1) The precision of Kriging Method is much more than IDW Method. (2) By Kriging Method the trend of rainfall changing is finely shown on an extend of larger scale but local changes in details cannot be represented whereas the IDW method lacks in precision but local changes in details can be well predicted by this method. Therefore, in the interpolation process the IDW method can be used to depict the local detailed information whereas to depict the whole rainfall trend Kriging method can be used as shown in Fig. 6. (3) Kriging method of interpolation has a tendency of underprediction of large values and over prediction of small values as it is observed from Fig 5. Here the blue line represent the fitted line amongst the various scattered points. Also the slope of the blue line is less than 1 as observed here. (4) Amongst the two methods the highest precision of interpolation is for Kriging method.

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