ESTIMATION AND VALIDATION OF WIND SPEED BY USING SPATIAL INTERPOLATION

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ESTIMATION AND VALIDATION OF WIND SPEED
BY USING SPATIAL INTERPOLATION

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
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JUNE 2015

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Civil Engineering (Hons.).

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DEDICATION

I would like to dedicate this thesis to my family
for their love, support and devotion,
making me to be who I am today.

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ABSTRACT

The increasing of wind hazard damages in Malaysia shows that wind speed has played an important role in weather forecast. Interpolation method is vital when estimating wind speed especially for a location which do not has a weather forecast station. In this study, three methods of spatial interpolation which are Inverse Distance Weighting (IDW), Kriging and Spline were compared to determine their suitability for estimating wind speed. All the methods are evaluated by using standard error regression and correlation coefficient analysis. Based on the results obtained, it was shown that Kriging is more suitable when estimating wind speed for a study point within an enclosed area while IDW and Spline are more suitable for study point between two locations. Therefore, the suitability of different spatial interpolation method is varies for different arrangements of location. Future studies with more data collected, denser sample points and different cases can be carried out to obtain a more accurate result.

ABSTRAK

Kerosakan yang disebabkan oleh bencana angin yang semakin meningkat di Malaysia menunjukkan kelajuan angin memainkan peranan yang penting dalam rekabentuk terhadap bangunan. Kaedah interpolasi adalah sangat penting apabila membuat anggaran kelajuan angin terutama bagi lokasi yang tidak mempunyai stesen ramalan cuaca. Dalam kajian ini, tiga kaedah interpolasi spatial iaitu 'Inverse Distance Weighting' (IDW), 'Kriging' dan 'Spline' telah dibanding untuk menentukan kesesuaian kaedah-kaedah tersebut dalam menganggarkan kelajuan angin. Semua kaedah dinilai dengan menggunakan regresi ralat piawai dan analisis koefisien korelasi. Berdasarkan keputusan yang diperolehi, ia menunjukkan bahawa kaedah 'Kriging' adalah lebih sesuai bagi menganggarkan kelajuan angin dalam kawasan yang tertutup manakala kaedah IDW dan 'Spline' lebih sesuai untuk titik kajian antara dua lokasi. Oleh itu, kesesuaian kaedah interpolasi spatial adalah berbeza bagi susunan lokasi yang berbeza. Di masa hadapan adalah dicadangkan supaya kajian mengguna pakai lebih banyak data.

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LIST OF SYMBOLS

Km/hr	Kilometers per hour
S	Standard error of regression
r	Correlation coefficient
$\hat{Z}(s_o)$	Predicted and observed value at location s_o
$Z(s_i)$	Predicted and observed value at location s_i,
N	Number of measured sample points used in the prediction
$w(d)$	Weighting function
d_i	Distance from s_o to s_i
$N(h)$	Number of pairs of measurement points with distance h apart
Σ	Sum
°E	Longitude
°N	Latitude

LIST OF ABBREVIATIONS

UMP	Univeristi Malaysia Pahang
GIS	Geographical Information System
IDW	Inverse Distance Weighting
MMD	Malaysian Meteorological Department
ESRI	Environmental System Research Institute

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Wind is flowing of air in our atmosphere caused by difference in air pressure where the greater the differences in air pressure, the faster the air flows. Wind has two characteristics namely wind speed and wind direction. Wind speed can be measured by using anemometer and wind speed data can be collected at meteorological station. There are various types of wind such as breeze, crosswind, gust, monsoon, tornado, typhoon, whirlwind and windstorm. A gentle wind is nice but a strong wind might cause damages.

Wind hazard damages in Malaysia has been increasing every year and various wind hazard damages has been reported by Malaysian Meteorological Department (MMD). On 16th July 2013, a strong wind hit West Coast of Sabah and Labuan resulted in fallen trees in various areas, causing damage to houses and vehicles, as well as traffic congestion. Meanwhile, power disruptions caused by trees and branches that had fallen on electric cables were also reported. The highest wind speed of 74 km/hr was reported by Kota Kinabalu Meteorological Station. (MMD Weather Report, 2013)

Besides, on 29th September 2014 and 21st October 2014, strong wind and thunderstorm had occurred in Bukit Jelutong, Shah Alam and Pandamaran, Klang respectively. The roof tiles of houses were blown off and cars were damaged by fallen trees. Other than that, a tornado had occured in Kampung Sungai Nonang, Kota Sarang Semut, Alor Setar on 12th November 2014. According to the report, this small scale of tornado resulted in many fallen trees and roof damage of around 20 houses and 4 shop-houses. (MMD Weather Report, 2014)

Figure 1.1: Damages caused by the tornado in Kampung Sungai Nonang

Source: Harian Metro, 12th November 2014

This shows that wind has played an important role in weather forecast. In order to prevent more wind hazard damages occur, it is important to forecast wind speed for a location. Since not all the places around Malaysia has meteorological station, obtaining wind speed at a location without meteorological station requires some form of spatial interpolation. Spatial interpolation by using Geographical Information System (GIS) can be used to estimate wind speed for a location. A variety of interpolation methods are available but accuracy vary among methods depending on the spatial attributes of the data.

1.2 PROBLEM STATEMENT

Before constructing any building or structure, it is important to determine the wind direction and wind speed for that location. Engineer can design the building or structure with higher resistance to the wind speed. This can prevent or reduce wind hazard damages that might occur for that location. However, not every place has meteorological station, so estimation of wind speed by using interpolation is vital especially for location without meteorological station.

There are various spatial interpolation methods, such as Inverse Distance Weighting (IDW), Kriging, Natural Neighbour, Spline, Topo to Raster, and Trend. Different methods have different conditions and produce different results. Furthermore, wind speed data of known locations are required to estimate wind speed at unmeasured locations. The arrangement of known locations which have meteorological station are not consistent and might give different results when carrying out different interpolation methods.

1.3 OBJECTIVE

The suitability to estimate wind speed for a location by using different spatial interpolation methods with different arrangements of known location need to be determined. Therefore, there are two objectives in this study which are:

i. To interpolate wind speed by using three different methods of interpolation namely IDW, Kriging and Spline.
ii. To identify the best fit method to interpolate for different arrangements of location around Peninsular Malaysia, Singapore and Indonesia.

1.4 SCOPE OF STUDY

The scope of this study is to determine the ways to succeed the objectives. The scopes of this study are:

i. 10 locations around Peninsular Malaysia, Singapore and Indonesia.
ii. Locations are divided into either study point within an enclosed area (Figure 1.2) or study point between two locations (Figure 1.3).
iii. Three interpolation methods compared are IDW, Kriging, and Spline.

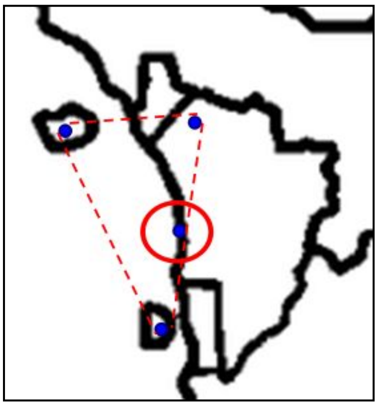

Figure 1.2: Study point within an enclosed area

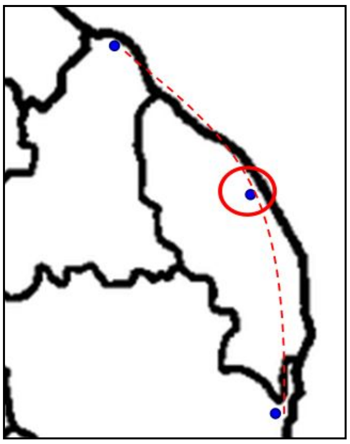

Figure 1.3: Study point between two locations

1.5 AREA OF STUDY

The area of study is limited to certain states in Peninsular Malaysia, Singapore and Indonesia. The 10 locations chosen are the meteorological station of the airport in the respective states (Figure 1.4).

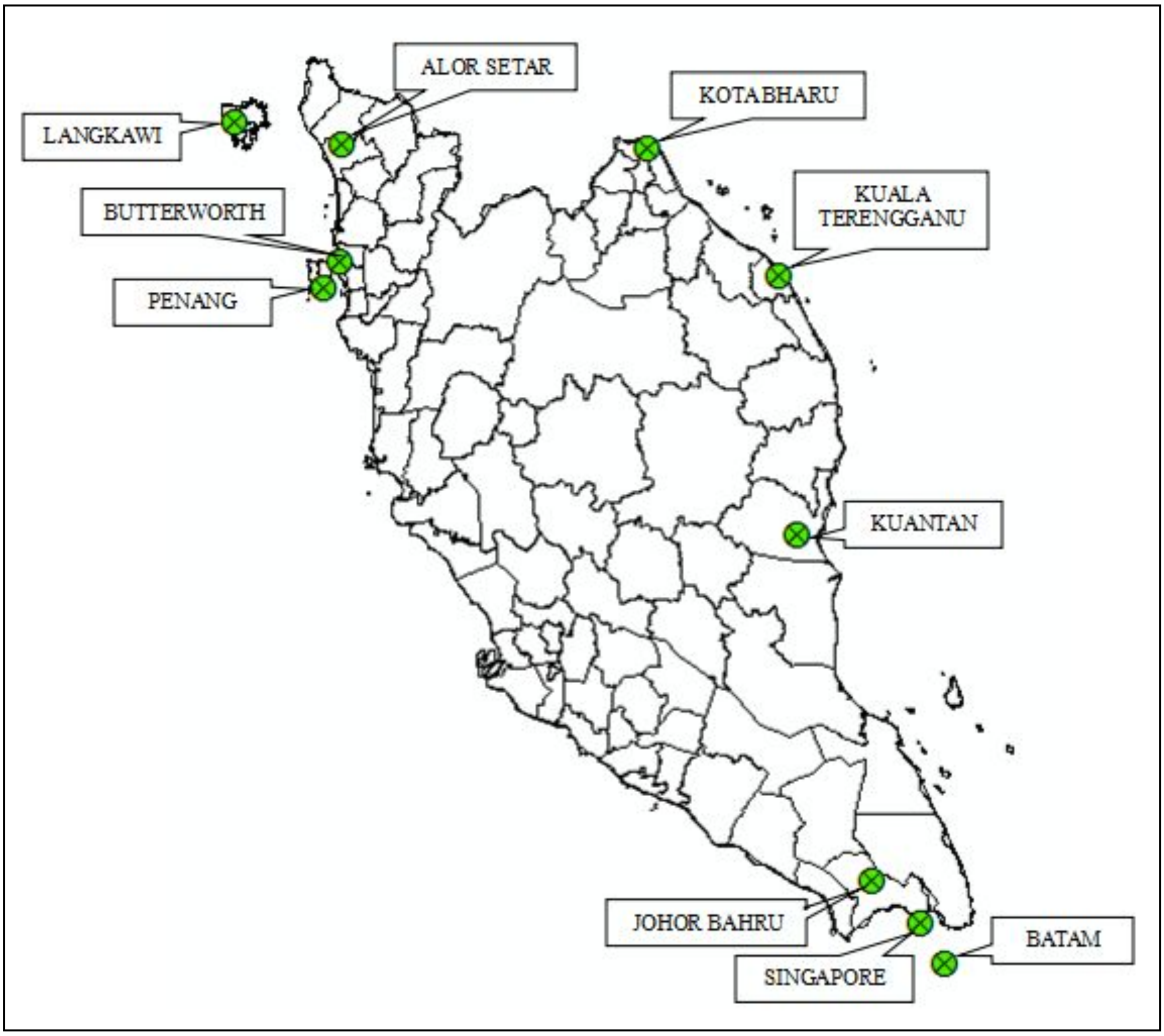

Figure 1.4: 10 locations chosen for this research

1.6 RESEARCH SIGNIFICANT

By carrying out this study, the suitability to estimate wind speed for a location with different arrangements of known location by using different interpolation methods can be determined. This can be a simple guideline when using spatial interpolation to estimate wind speed for a location. For example, if the study point is within an enclosed area of known locations, a specified interpolation method is more suitable to be used. On the other hand, if the study point is between two known locations, another specified interpolation method will be more suitable.

1.7 THESIS LAYOUT

There are five chapters in this thesis:

i. CHAPTER 1 : Introduction
   This chapter shows the background, overview of problem statement, objective, scope of study, study area and research significant.
ii. CHAPTER 2 : Literature Review
   This chapter shows a review of past research related to the objective of study.
iii. CHAPTER 3 : Methodology
   This chapter shows the research method used in this study
iv. CHAPTER 4 : Result and Discussion
   This chapter shows the results obtained and discussion based on the results.
v. CHAPTER 5 : Conclusion and Recommendation
   This chapter shows the conclusion for this study and provides some future recommendation to improve the results obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provide a review of past research related to estimation of wind speed by using interpolation in. A review of other relevant research studies about spatial interpolation is also provided. This review will focus on wind and spatial interpolation.

2.2 WIND

Wind is flowing of air in our atmosphere caused by uneven heating of Earth by the sun. Wind cannot be seen or caught but we can feel its force, thus it is usually described by its direction and speed. It is a very good equalizer for the atmosphere, transporting heat, moisture, pollutants, and dust. The differences in atmospheric pressure produce wind. Generally, wind flow from high pressure areas to low pressure areas

2.2.1 Types of Wind

As wind travels at different speeds, altitudes and over water or land, thus it can cause different types of patterns. There are various types of wind such as breeze, crosswind, gust, monsoon, tornado, typhoon, whirlwind and windstorm. A gentle wind is nice but a strong wind might cause damages.

2.2.2 Wind Speed

Wind speed is the measure of the air motion with respect to the surface of earth covering a unit distance over a unit time. In Malaysia, wind speed is usually measured in kilometer per hour. An anemometer is a device used to measure wind speed.

The amount of force that wind is generating is measured according to the Beaufort scale. The scale is named for Sir Francis Beaufort, who established the system for describing wind force in 1805 for the British Royal Navy. The Beaufort scale has 17 levels of wind force (National Geographic Education).

2.2.3 Wind Hazard Damages

Wind hazard damages are natural disaster caused by strong wind. Wind hazard include hurricanes, tornadoes, typhoon and other windstorms are threats to many places around the world causing damages such as high levels of injuries, deaths, property damages, and business interruption. In Malaysia, wind hazards such as strong wind, gale and small scale tornado can be found. Gale often happens around urban area.

From the weather reports for year 2013 and 2014 by MMD, most of the wind hazard damages caused by gale and thunderstorm were from Klang Valley. On 29^{th} September 2014, more than 100 houses experienced roof damages and cars are damaged by fallen trees in Shah Alam. On 12^{th} October 2014, the thunderstorm occurred in Kuala Lumpur causes the death of two policemen after the trailers used to store case objects are struck by fallen trees. On 21^{st} October 2014, the strong wind in Pandamaran, Klang causing damages to around 30 houses.

Furthermore, small scale of tornado often spotted in Alor Setar, Kedah. On 14^{th} October 2014 and 12^{th} November 2014, many houses were damaged and fallen trees were everywhere due to the tornado. From the weather report, it stated that this tornado was caused by unstable atmosphere with high air humidity.

Figure 2.1: Tornado in Alor Setar

Source: Berita Harian Online, 14th October 2014

Figure 2.2: Damages caused by tornado in Alor Setar

Source: Malaysiakini 12th November 2014

2.3 SPATIAL INTERPOLATION

Spatial interpolation is the prediction of variables at unmeasured locations based on samples at known locations. Spatial interpolation method by using GIS can be used when estimating wind speed for a location. There are various spatial interpolation methods such as IDW, Kriging. Natural Neighbor, Spline, Topo to Raster, and Trend.

Weather data are generally recorded at point locations, so some form of spatial interpolation is required to estimate data values at other locations. A variety of deterministic and geo-statistical interpolation methods are available to estimate unmeasured locations but, depending on the spatial attributes of the data, accuracy vary widely among methods. The final use of any interpolated variable surface must also be taken into account because different methods result in different surfaces (Willmott, 1984)

Spatial interpolation is more worthwhile if a sufficient density of weather stations is available across the study area. The density of the network required depends upon the variable to be estimated. Wind speed, for example, is more variable over shorter distances than temperature or relative humidity, and hence would be expected to require a more dense network of monitoring sites to achieve accurate and precise interpolated surfaces (Luo et al.,2008).

Spatial continuous data play an important role in planning, risk assessment, and decision-making in environmental management. However, they are usually not always readily available and often expensive and difficult to obtain. Environmental data collected on field surveys are typically from point sources. Environmental managers often require spatial continuous data over a region of interest to make effective decisions, and scientists need accurate spatial continuous data across a region to make justified interpretations (Chinta, 2014).

W. Luo et al. (2008) stated that there is a need to estimate the risk posed by the spreading of existing and invading non-indigenous pathogens or insects across the landscape. Studies on the risks posed by these pathogen and pests need to estimate how frequently wind speeds above various thresholds could be expected to push them between hosts. Rather than use the point value from the nearest recording station, which may be many kilometers distant (Luo et al., 2008).

There are many researches on comparison of interpolation methods for temperature and precipitation, (Phillips et al., 1992; Collins and Bolstad, 1996; Goovaerts, 2000; Price et al., 2000; Jarvis and Stuart, 2001; Vicente-Serrano et al., 2003; Chai et al, 2011) but few research effort have been directed towards comparing the effectiveness of different spatial interpolation methods in estimating wind speed.

When compared with other interpolation methods evaluated, cokriging was most likely to produce the best estimation of a continuous surface for wind speed and that result had temporal consistency (Luo et al., 2008). On the other hand, Sandeep Chinta (2014) stated that global polynomial interpolation was most likely to produce the suitable estimation of a continuous surface for wind speed (Chinta, 2014).

2.3.1 Inverse Distance Weighting (IDW)

The IDW function should be used when the set of point is dense enough to capture the extent of local surface variation needed for analysis. IDW determines cell values using a linear-weighted combination set of sample points. The weight assigned is a function of the distance of an input point from the output cell location. The greater the distance, the less influence the cell has on the output value (Colin Childs, 2004).

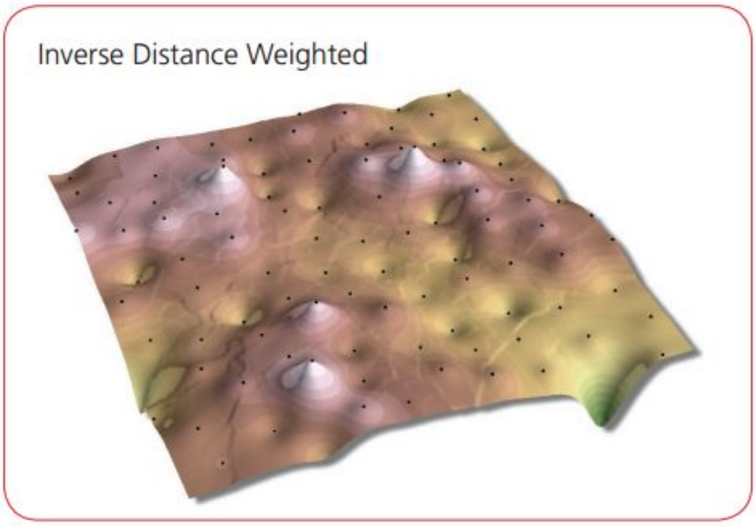

Figure 2.3: Inverse Distance Weighting

Source: ESRI Education Services (2004)

IDW interpolation combines the idea of proximity espoused by Thiessen Polygons (Thiessen, 1911) with the gradual change of a trend surface. Those measured values closest to the prediction location will have more influence on the predicted value than those further away. This distance-decay approach has been applied widely to interpolate climatic data (Legates and Willmott, 1990; Stallings et al., 1992). IDW assumes that each measured point has a local influence that diminishes with distance. The usual expression is expressed as in Eq. (2.1)

$$\hat{Z}(s_o) = \left[\sum_{i=1}^{N} w(d_i) Z(s_i)\right] \Big/ \left[\sum_{i=1}^{N} w(d_i)\right] \tag{2.1}$$

where $\hat{Z}(s_o)$, $Z(s_i)$ represent the predicted and observed value at location s_o, s_i,

N is the number of measured sample points used in the prediction,

$w(d)$ is the weighting function,and

d_i is the distance from s_o to s_i

Based on the structure of IDW expression, the choice of weighting function can significantly affect the interpolation results. The comparative merits of various wieghting functions are discussed in detail by Lancaster and Salkaukas (1986). The IDW parameters specified in ArcGIS are the power option, search shape, search radius and number of points. A circle with radius 100 km for each shape with minimum and maximum numbers of points of 10 and 15 were specified for IDW. The power was optimized automatically by ArcGIS.

2.3.2 Kriging

A powerful statistical interpolation method used for diverse applications such as health sciences, geochemistry, and pollution modeling. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. It fits a function to a specified number of points or all points within a specified radius to determine the output value for each location. Kriging is most appropriate when a spatially correlated distance or directional bias in the data is known and is often used for applications in soil science and geology (Colin Childs, 2004).

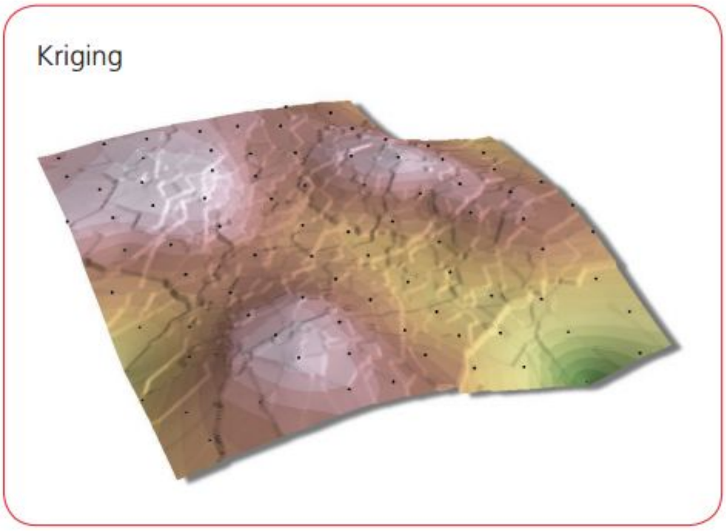

Figure 2.4: Kriging

Source: ESRI Education Services (2004)

Kriging (Krige, 1996) is a stochastic technique similar to IDW, in that it uses a linear combination of weights at known points to estimate the value at an unknown point. In contrast with deterministic methods, Kriging provides a solution to the problem of estimation of the surface by taking account of the spatial correlation. The spatial correlation between the measurement points can be quantified by means of the semi-variance function as in Eq. (2.2)

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(s_i) - Z(s_i + h) \right]^2 \qquad (2.2)$$

where *N(h)* is the umber of pairs of measurement points with distance *h* apart

Varieties of Kriging have been developed such as ordinary, universal, simple, and indicator, but only the first one is used in this study. Ordinary Kriging which assumes the mean is unknown, focuses on the spatial component and uses only the samples in the local neighborhood for the estimate. Universal Kriging is similar to that of ordinary Kriging, but assumes the presence of a trend in average values across the study area.

2.3.3 Spline

Spline estimates values using a mathematical function that minimizes overall surface curvature. This results in a smooth surface that passes exactly through the input points. Consequently, it is like bending a sheet of rubber so that it passes through the points while minimizing the total curvature of the surface. It can predict ridges and valleys in the data and is the best method for representing the smoothly varying surfaces of phenomena such as temperature (Colin Childs, 2004).

There are two variations of spline - regularized and tension. A regularized spline incorporates the first derivative - slope; second derivative - rate of change in slope; and third derivative - rate of change in the second derivative; into its minimization calculations. Although a tension spline uses only first and second derivatives, it includes more points in the spline calculations, which usually creates smoother surfaces but increases computation time (Colin Childs, 2004).

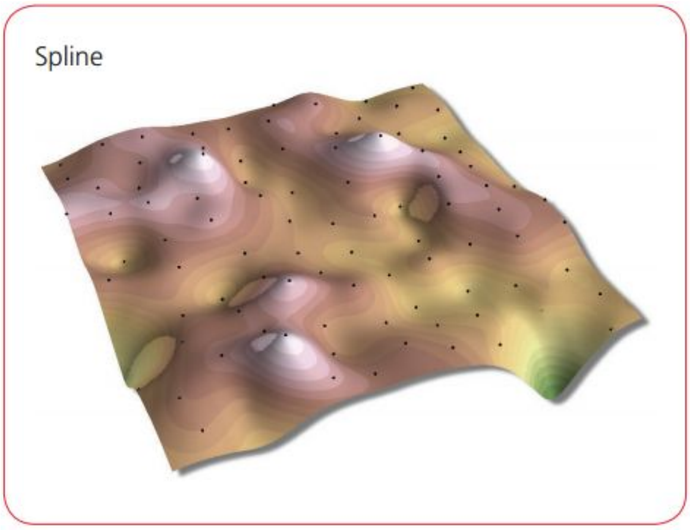

Figure 2.5: Spline

Source: ESRI Education Services (2004)

Spline is a commonly used deterministic interpolation method to represent two-dimensional curves on three-dimension surfaces. The Spline method produces good results for gently varying surfaces such as rainfall. Spline is not suitable when there are large changes in the surface values within a short horizontal distance (Yang et al., 2004).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The aim of this chapter is to discuss the research method used in this study. There are four major phases in this research methodology, which are:

i. Data collection
   The location of meteorological station and wind speed data are collected.
ii. Pre-processing data
   The locations are divided into cases and a database that contains location and wind speed is created.
iii. Processing data
   Different spatial interpolation is carried out.
iv. Output
   Interpolated wind speed data for different cases

In this chapter, phases i, ii, and iii will be discussed. Meanwhile, phase iv will be discussed in Chapter 4. The flowchart of this research methodology is as shown in Figure 3.1.

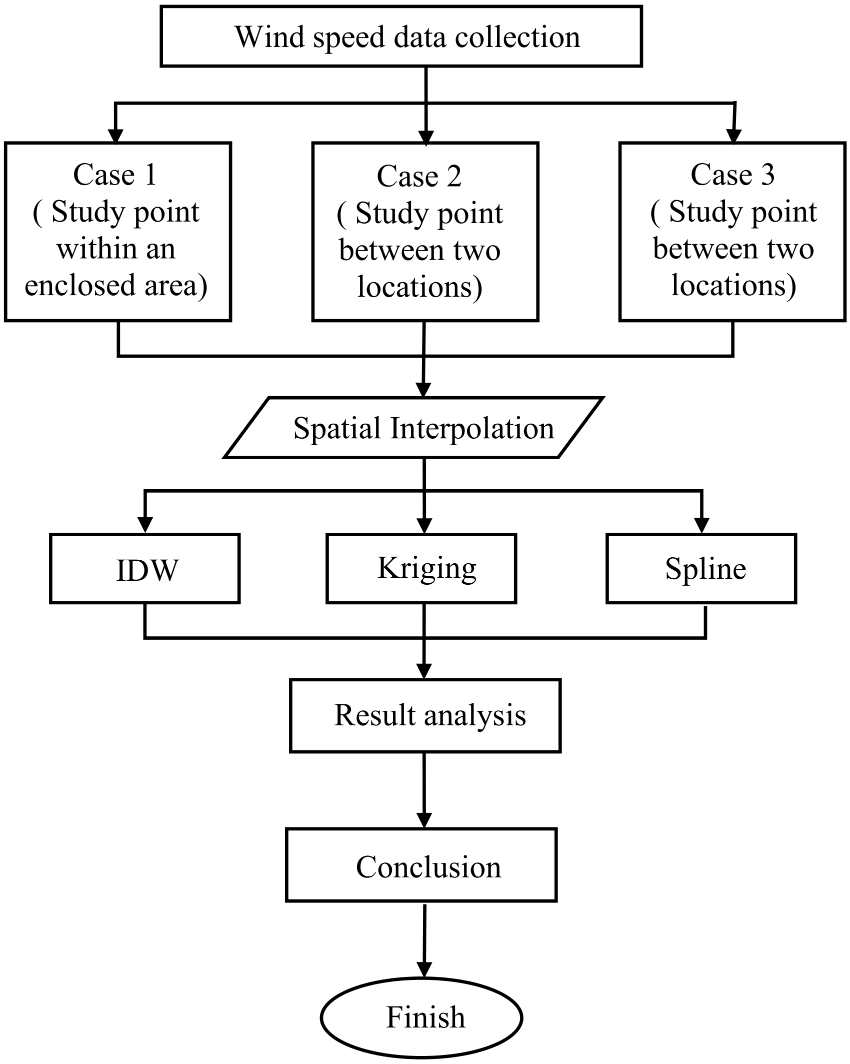

Figure 3.1: Research methodology flowchart

3.2 DATA COLLECTION

The main information that needed in this study is location and wind speed. All the locations and wind speed data are collected from MMD. The wind speed is from the meteorological stations around Peninsular Malaysia, Singapore and Indonesia.

3.2.1 Locations of Meteorological Station

The 10 locations chosen are meteorological stations in the airport of the respective states from Peninsular Malaysia, Singapore and Indonesia. This is because, the weather data obtained from the meteorological station in the airport are usually more accurate. Furthermore, the locations chosen are based on their arrangements of location to carry out interpolation. The coordinates of 10 locations chosen are shown in Table 3.1 below.

Table 3.1: Coordinates of 10 meteorological stations chosen

Location	Latitude (°N)	Longitude (°E)
Langkawi	6.33	99.73
Alor Setar	6.19	100.40
Butterworth	5.47	100.39
Penang	5.30	100.28
Johor Bahru	1.64	103.67
Singapore	1.37	103.98
Batam	1.12	104.12
Kuantan	3.78	103.21
Kuala Terengganu	5.38	103.10
Kota Bharu	6.17	102.29

3.2.2 Wind Speed

In this study, maximum monthly wind speed for Year 2013 and 2014 are used. Firstly, the daily wind speed for every month which is from January 2013 to December 2014 are collected for all 10 meteorological stations. Then, the maximum wind speed for each month for the 10 locations are tabulated in the table (Table 3.2).

Table 3.2: Maximum wind speed for each month in Year 2013 and 2014 (km/hr)

Location	YEAR 2013											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Langkawi	24	24	27	26	21	24	19	27	23	24	26	23
Alor Setar	24	26	21	26	24	27	26	29	27	26	23	19
Butterworth	27	37	35	27	26	42	29	24	24	26	27	29
Penang	29	26	26	26	32	29	29	40	27	27	24	29
Johor Bahru	26	23	27	27	32	21	19	23	19	23	32	24
Singapore	27	24	24	26	26	26	35	29	24	26	24	26
Batam	44	37	148	21	24	27	27	34	27	27	26	37
Kuantan	23	19	19	24	24	35	32	34	27	27	24	23
Kuala Terengganu	27	24	19	27	26	19	35	34	29	32	26	27
Kota Bharu	26	35	26	24	14	40	35	34	35	76	35	34
Location	YEAR 2014											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Langkawi	24	27	29	26	19	21	29	23	23	23	27	27
Alor Setar	23	23	27	23	27	23	27	23	29	29	24	21
Butterworth	26	24	23	27	29	26	24	26	27	37	32	37
Penang	27	34	26	29	29	24	27	42	39	27	32	27
Johor Bahru	24	27	26	26	32	19	19	26	23	27	24	32
Singapore	27	27	29	32	27	24	26	42	34	29	26	47
Batam	40	47	39	29	29	35	34	32	34	32	55	39
Kuantan	21	19	23	27	32	29	26	37	27	39	19	24
Kuala Terengganu	29	19	19	16	32	32	32	19	16	23	27	32
Kota Bharu	34	29	34	24	26	26	26	21	29	21	21	61

3.3 PRE-PROCESSING DATA

The locations are divided into different cases and a database contain wind speed and location is created..

3.3.1 Different Cases of Arrangements of Location

In order to find the suitability of estimating wind speed by using interpolation with different arrangements of location, the 10 locations are divided into three cases. The cases are either study point within an enclosed area or study point is between two locations. The three cases are:

i. Case 1: Study point within an enclosed area
   - Locations involved : Langkawi, Alor Setar, Penang, Butterworth
   - Study point : Butterworth

ii. Case 2: Study point between two locations
   - Locations involved : Kota Bharu, Kuala Terengganu, Kuantan
   - Study point : Kuala Terengganu

iii. Case 3: Study point between two locations
   - Locations involved : Johor Bahru, Singapore, Batam
   - Study point : Singapore

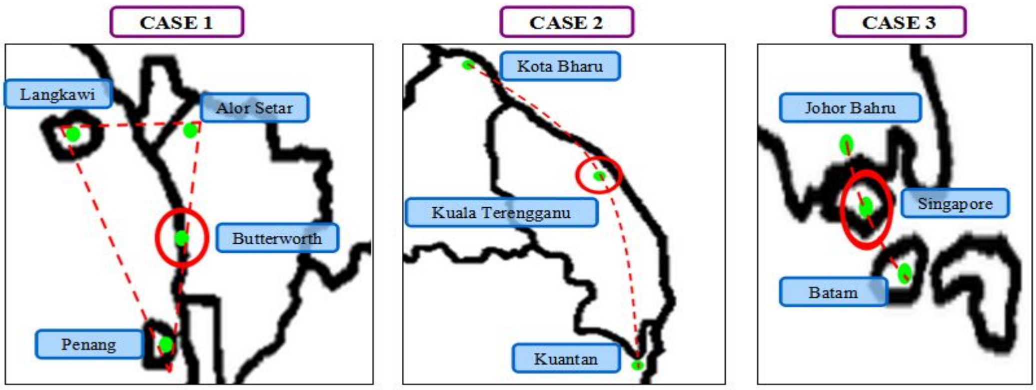

Figure 3.2: Different cases of arrangements of locations

3.3.2 Database for Locations and Wind Speed

Table 3.3: Wind speed data for Case 1 (km/hr)

YEAR 2013												
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Langkawi	24	24	27	26	21	24	19	27	23	24	26	23
Alor Setar	24	26	21	26	24	27	26	29	27	26	23	19
Butterworth	27	37	35	27	26	42	29	24	24	26	27	29
Penang	29	26	26	26	32	29	29	40	27	27	24	29

YEAR 2014												
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Langkawi	24	27	29	26	19	21	29	23	23	23	27	27
Alor Setar	23	23	27	23	27	23	27	23	29	29	24	21
Butterworth	26	24	23	27	29	26	24	26	27	37	32	37
Penang	27	34	26	29	29	24	27	42	39	27	32	27

Table 3.4: Wind speed data for Case 2 (km/hr)

YEAR 2013												
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Kuantan	23	19	19	24	24	35	32	34	27	27	24	23
Kuala Terengganu	27	24	19	27	26	19	35	34	29	32	26	27
Kota Bharu	26	35	26	24	14	40	35	34	35	76	35	34

YEAR 2014												
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Kuantan	21	19	23	27	32	29	26	37	27	39	19	24
Kuala Terengganu	29	19	19	16	32	32	32	19	16	23	27	32
Kota Bharu	34	29	34	24	26	26	26	21	29	21	21	61

Table 3.5: Wind speed data for Case 3 (km/hr)

YEAR 2013												
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Johor Bahru	26	23	27	27	32	21	19	23	19	23	32	24
Singapore	27	24	24	26	26	26	35	29	24	26	24	26
Batam	44	37	148	21	24	27	27	34	27	27	26	37

YEAR 2014												
Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Johor Bahru	24	27	26	26	32	19	19	26	23	27	24	32
Singapore	27	27	29	32	27	24	26	42	34	29	26	47
Batam	40	47	39	29	29	35	34	32	34	32	55	39

3.4 PROCESSING DATA

The spatial interpolation is carried out by using the Spatial Analyst Tools. In this study, three spatial interpolation methods which are Inverse Distance Weighting (IDW), Kriging and Spline are compared to determine their suitability in estimating wind speed for different arrangements of location. For this purpose, ArcGIS are used to conduct the analysis.

3.4.1 Spatial Interpolation

Three spatial interpolation methods which are IDW, Kriging and Spline are carried out for all three different cases. For Case 1 which is study point within an enclosed area, all three interpolation method can be carried out . However, for Case 2 and Case 3 which are study point between two locations, Kriging method failed to execute.

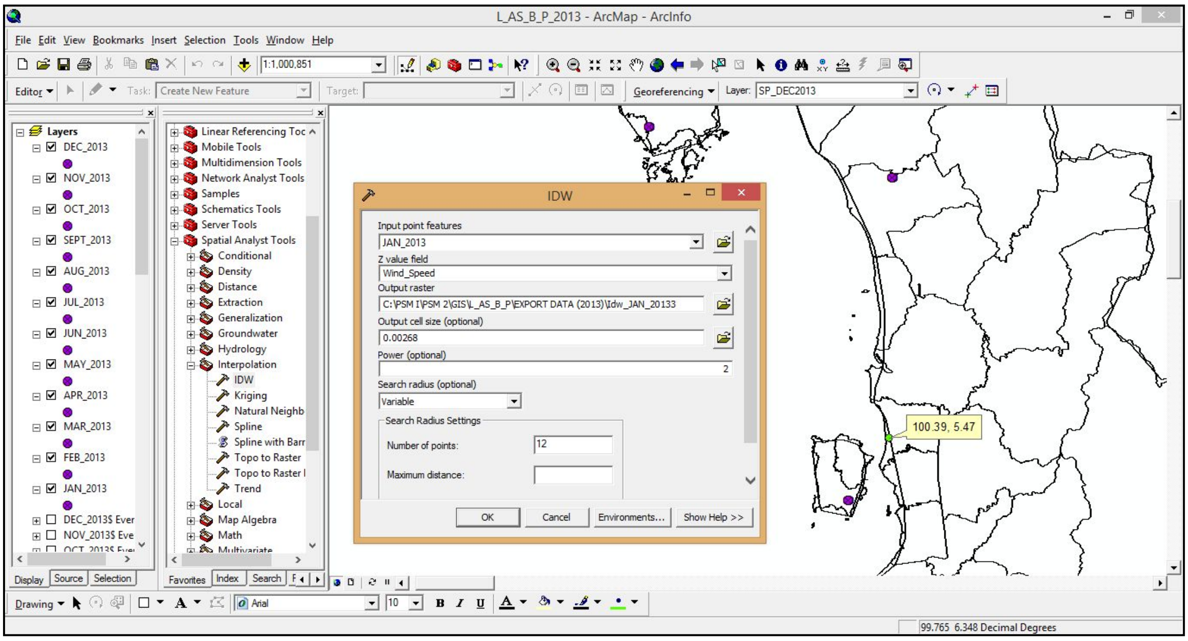

Figure 3.3: One of the IDW method

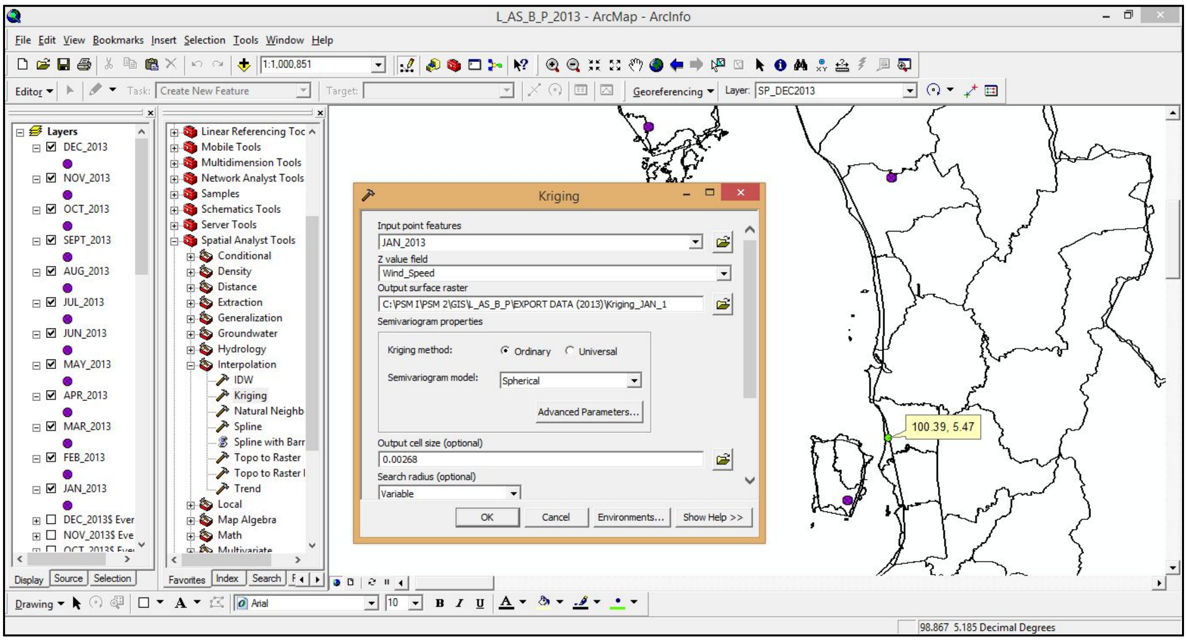

Figure 3.4: One of the Kriging method

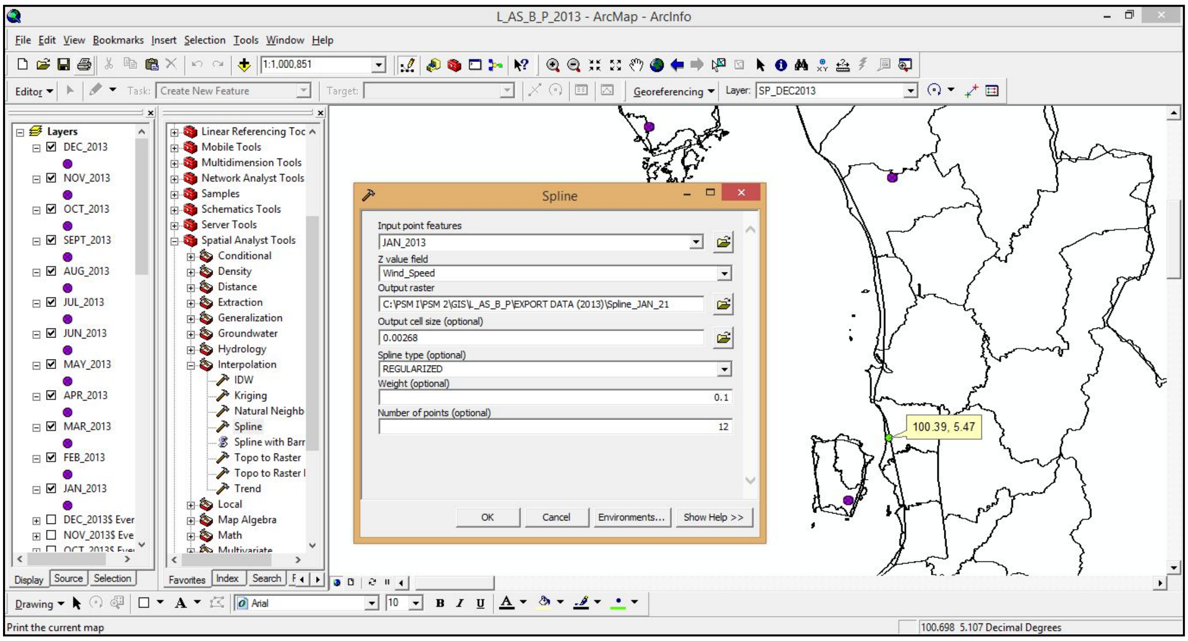

Figure 3.5: One of the Spline method

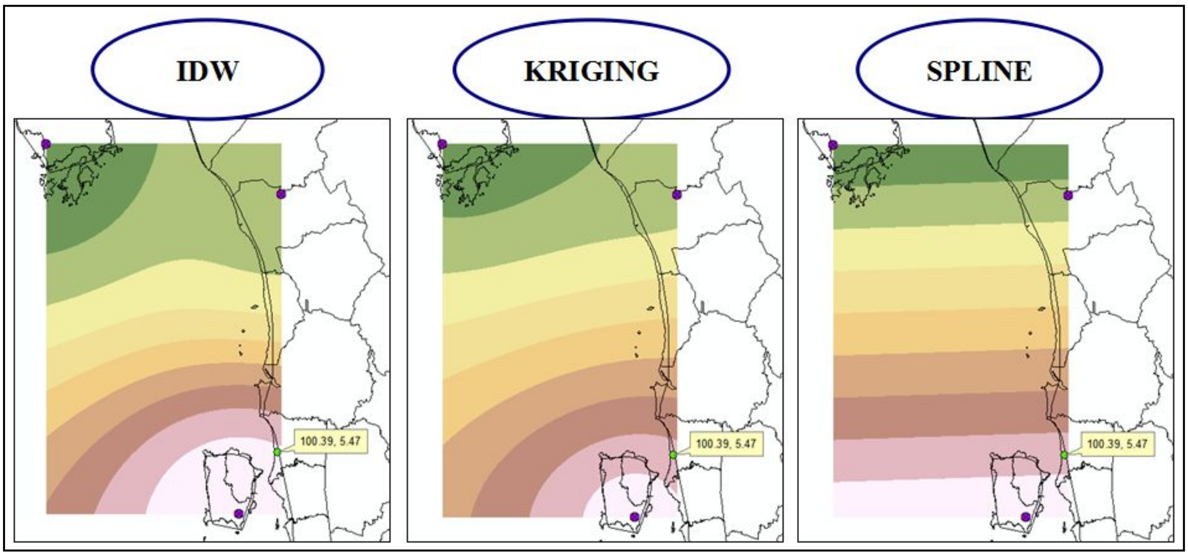

Figure 3.6: Some of the interpolation maps for study point within an enclosed area

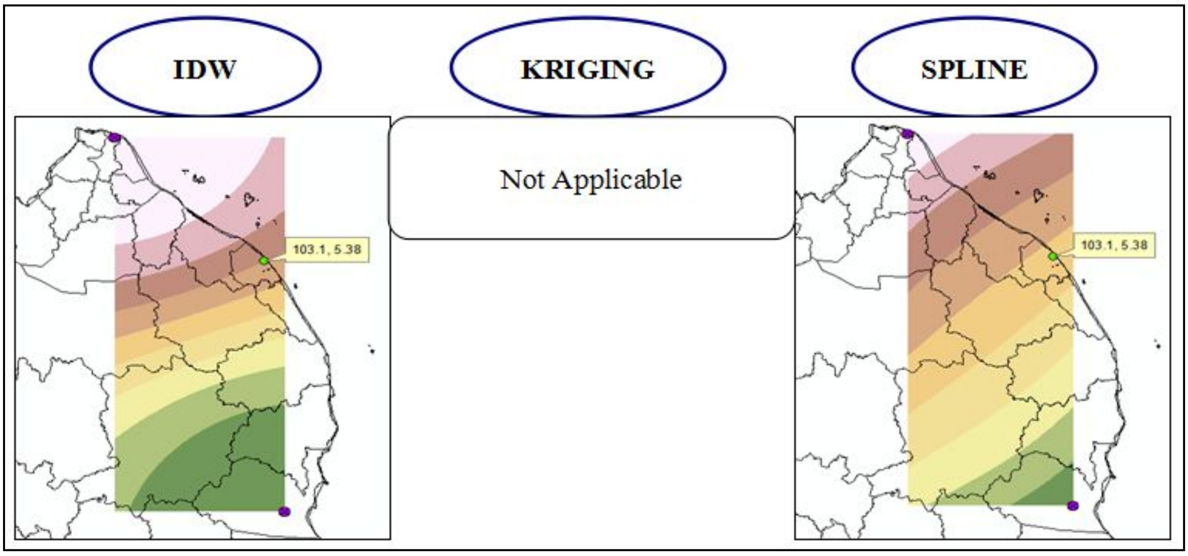

Figure 3.7: Some of the interpolation maps for study point between two locations

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

All the outputs or results from Chapter 3 is shown and analyzed in this chapter. Both objectives of this study were carried out successfully. The objectives are:

i. To interpolate wind speed by using three different methods of interpolation namely IDW, Kriging and Spline.
ii. To identify the best fit method to interpolate for different arrangements of location around Peninsular Malaysia, Singapore and Indonesia.

4.2 INTERPOLATED WIND SPEED

For the period of two year, which is from January 2013 to December 2014, all the maximum monthly wind speed of the study point collected from the meteorological station were tabulated in the table as “Recorded” values. Then, the results from the interpolation by using GIS or the interpolated wind speed of the study point were tabulated in the table as “Predicted” values. The tables are divided into different cases with different years and the results from the three interpolation methods were compared inside these tables.

Table 4.1: Interpolated wind speed results for Case 1 (Year 2013)

YEAR 2013	IDW		KRIGING		SPLINE	
	RECORDED	PREDICTED	RECORDED	PREDICTED	RECORDED	PREDICTED
JANUARY	27	28.495808	27	27.945259	27	27.952682
FEBRUARY	37	25.938158	37	25.714203	37	26.251177
MARCH	35	25.681332	35	25.428408	35	24.199152
APRIL	27	26.000000	27	ERROR	27	26.000000
MAY	26	31.100533	26	30.238211	26	30.701059
JUNE	42	28.705561	42	28.415567	42	28.957840
JULY	29	28.481041	29	26.408102	29	29.250731
AUGUST	24	38.828938	24	37.630100	24	37.947079
SEPTEMBER	24	26.876318	24	26.428408	24	27.502354
OCTOBER	26	26.837320	26	26.366205	26	27.041714
NOVEMBER	27	23.991924	27	24.142899	27	23.413771
DECEMBER	29	28.115299	29	27.002996	29	26.403011

Table 4.1 shows the results for Case 1 in Year 2013. All three methods of interpolation can be carried out. However, for Kriging method there is an error for the result in April 2013. By referring to Table 3.3, the wind speed collected for April 2013 for all three known locations are the same, 26 km/hour. This probably causes error to interpolate wind speed by using Kriging method.

Table 4.2: Interpolated wind speed results for Case 1 (Year 2014)

YEAR 2014	IDW		KRIGING		SPLINE	
	RECORDED	PREDICTED	RECORDED	PREDICTED	RECORDED	PREDICTED
JANUARY	26	26.627567	26	26.180943	26	26.036558
FEBRUARY	24	33.014462	24	31.785002	24	31.193548
MARCH	23	26.162680	23	26.633795	23	25.958286
APRIL	27	28.487732	27	27.394058	27	27.366453
MAY	29	28.550959	29	25.214617	29	29.585783
JUNE	26	23.837320	26	23.366205	26	24.041714
JULY	24	27.061842	24	27.285797	24	26.748823
AUGUST	26	40.084072	26	37.991985	26	38.020195
SEPTEMBER	27	37.806095	27	36.742107	27	37.658897
OCTOBER	37	27.016153	37	26.714203	37	28.172459
NOVEMBER	32	31.286055	32	30.392895	32	29.947527
DECEMBER	37	26.580494	37	26.142611	37	24.989687

Table 4.2 shows the results for Case 1 in Year 2014. All three methods of interpolation can be carried out.

Table 4.3: Interpolated wind speed results for Case 2 (Year 2013)

YEAR 2013	IDW		KRIGING		SPLINE	
	RECORDED	PREDICTED	RECORDED	PREDICTED	RECORDED	PREDICTED
JANUARY	27	25.004717	Not applicable		27	24.567862
FEBRUARY	24	29.691818			24	27.361933
MARCH	19	23.677671			19	22.658346
APRIL	27	24.000000			27	24.000000
MAY	26	17.317614			26	18.773792
JUNE	19	38.341194			19	37.613106
JULY	35	34.004715			35	33.567863
AUGUST	34	34.000000			34	34.000000
SEPTEMBER	29	32.345909			29	31.180967
OCTOBER	32	59.743694			32	52.608418
NOVEMBER	26	31.350626			26	29.748829
DECEMBER	27	30.350626			27	28.748829

Table 4.3 shows the results for Case 2 in Year 2013. All three methods of interpolation were carried out, but Kriging method failed to execute. This is because, Kriging suits to a specified number of points within a specified radius to determine the output value which shows that Kriging can only be carried out if the study point is within a specified area. It is not suitable to be carried out for study point between two locations.

Table 4.4: Interpolated wind speed results for Case 2 (Year 2014)

YEAR 2014	IDW		KRIGING		SPLINE	
	RECORDED	PREDICTED	RECORDED	PREDICTED	RECORDED	PREDICTED
JANUARY	29	29.687103	Not applicable		29	27.794071
FEBRUARY	19	25.682386			19	24.226208
MARCH	19	30.350626			19	28.748829
APRIL	16	24.995283			16	25.432138
MAY	32	27.990568			32	28.864275
JUNE	32	26.995283			32	27.432138
JULY	32	26.000000			32	26.000000
AUGUST	19	26.308182			19	28.638067
SEPTEMBER	16	28.336477			16	28.045242
OCTOBER	23	26.971704			23	29.592825
NOVEMBER	27	20.336477			27	20.045242
DECEMBER	32	48.724831			32	43.336971

Table 4.4 shows the results for Case 2 in Year 2014. All three methods of interpolation were carried out, but Kriging method failed to execute. This is because, Kriging suits to a specified number of points within a specified radius to determine the output value which shows that Kriging can only be carried out if the study point is within a specified area. It is not suitable to be carried out for study point between two locations.

Table 4.5: Interpolated wind speed results for Case 3 (Year 2013)

YEAR 2013	IDW		KRIGING		SPLINE	
	RECORDED	PREDICTED	RECORDED	PREDICTED	RECORDED	PREDICTED
JANUARY	27	38.096107	Not applicable		27	42.679935
FEBRUARY	24	32.408085			24	35.973282
MARCH	24	108.312721			24	139.126236
APRIL	26	22.967964			26	21.440022
MAY	26	26.623953			26	24.586695
JUNE	26	25.032036			26	26.559978
JULY	35	24.376047			35	26.413305
AUGUST	29	30.392065			29	33.193295
SEPTEMBER	24	24.376047			24	26.413305
OCTOBER	26	25.688025			26	26.706652
NOVEMBER	24	27.967964			24	26.440022
DECEMBER	26	32.736076			26	36.046619

Table 4.5 shows the results for Case 3 in Year 2013. All three methods of interpolation were carried out, but Kriging method failed to execute. This is because, Kriging suits to a specified number of points within a specified radius to determine the output value which shows that Kriging can only be carried out if the study point is within a specified area. It is not suitable to be carried out for study point between two locations.

Table 4.6: Interpolated wind speed results for Case 3 (Year 2014)

YEAR 2014	IDW		KRIGING		SPLINE	
	RECORDED	PREDICTED	RECORDED	PREDICTED	RECORDED	PREDICTED
JANUARY	27	34.752094	Not applicable		27	38.826611
FEBRUARY	27	40.440121			27	45.533260
MARCH	29	34.736076			29	38.046619
APRIL	32	28.016018			32	28.779989
MAY	27	29.983982			27	29.220011
JUNE	24	29.752096			24	33.826611
JULY	26	29.080090			26	32.899944
AUGUST	42	30.032036			42	31.559978
SEPTEMBER	34	30.392065			34	33.193295
OCTOBER	29	30.360029			29	31.633316
NOVEMBER	26	44.832184			26	52.726555
DECEMBER	47	36.704041			47	38.486641

Table 4.6 shows the results for Case 3 in Year 2014. All three methods of interpolation were carried out, but Kriging method failed to execute. This is because, Kriging suits to a specified number of points within a specified radius to determine the output value which shows that Kriging can only be carried out if the study point is within a specified area. It is not suitable to be carried out for study point between two locations.

4.3 STANDARD ERROR REGRESSION AND CORRELATION COEFFICIENT ANALYSIS

In order to analyze the relationship between the recorded value and predicted value, linear regression analysis is used. The best fit line or trend-line was drawn as close as possible to the points on the scatter diagram. In this study, standard error of the regression and correlation coefficient analysis were carried out.

Standard error, S represents the average distance that the observed values fall from the regression line. Conveniently, it shows how wrong the regression model is on average using the units of the response variable. Smaller values are better because it indicates that the observations are closer to the best fitted line.

The correlation coefficient, r measure the strength and direction of the linear relationship between two variables. The value of r ranges between -1 and 1. The greater the absolute value of r, the stronger the linear relationship.

Therefore, smaller S value and larger r value indicates the observation are closer to the best fit line. Consequently, the best fit method to interpolate wind speed for different arrangements of location can be determined. All the standard error of regression and correlation coefficient analysis results (Appendix A1, A2 and A3) were tabulated in the table according to different cases (Table 4.7).

Table 4.7: Standard error and correlation coefficient analysis results

CASE	YEAR	METHOD	*S*	*r*
1	2013	IDW	3.8329	0.2799
		KRIGING	3.6796	0.2875
		SPLINE	3.7866	0.2734
	2014	IDW	5.1286	0.1612
		KRIGING	4.7004	0.1834
		SPLINE	4.7418	0.1389
2	2013	IDW	10.3392	0.3547
		KRIGING	-	-
		SPLINE	8.5115	0.3860
	2014	IDW	6.8442	0.3056
		KRIGING	-	-
		SPLINE	5.4892	0.2831
3	2013	IDW	23.8012	0.2652
		KRIGING	-	-
		SPLINE	32.6988	0.2470
	2014	IDW	5.437	0.0633
		KRIGING	-	-
		SPLINE	7.2862	0.1741

From the table above (Table 4.7), it was clearly shown that Kriging has smaller S value and larger r value for Case 1 in both Year 2013 and 2014 compared to Kriging and Spline. This indicates that Kriging is more suitable when estimating wind speed for a location within an enclosed area. Kriging is unable to produce any result for the cases where study point is between two locations. This is due to Kriging method fits a function to a specified number of points within a specific radius.

On the other hand, both IDW and Spline show different results for Case 2 and Case 3 in different years. IDW determines cell values using a linear-weighted combination set of sample points, while Spline minimize the total curvature of the surface and passes through the input points. This shows that IDW and Spline are more suitable for study points between two locations.

4.4 SUMMARY

Three interpolation methods were carried out for all three cases by using GIS. However, not all the method can be executed and produces result. The results show that Kriging can only be executed for study point within a specific area, it is unable be executed when the study point is between two locations. This also explained why Kriging shows lower *S* value and higher *r* value in the linear regression analysis for Case 1 which is study point within an enclosed area.

Besides, since Kriging is unable to be executed for Case 2 and Case 3 where the study point is between two locations, only IDW and Spline results can be compared. However, both of the methods show different results in different years. Therefore, IDW and Spline are both suitable to be used when estimating wind speed for study point between two locations.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This study is carried out to estimate and validate wind speed by using interpolation in GIS around Peninsular Malaysia, Singapore and Indonesia. In this chapter, the conclusion and recommendation for this study will be discussed. The conclusion is to achieve the objectives of this study which have been stated in Chapter 1 section 1.3.

5.2 CONCLUSION

Due to the increasing wind hazard damages in Malaysia, wind speed has played an important role in weather forecast. Before constructing any building or structure, it is important to determine the wind speed for that location This enables engineers to design the building or structure with higher resistance to the wind speed and prevent or reduce wind hazard damages.

However, meteorological stations are not easily to be found for every location. Therefore, to estimate wind speed for a location without a meteorological station, spatial interpolation by using known data from nearby meteorological station can be carried out. Furthermore, there are various interpolation methods, thus it is important to determine the suitability of the interpolation method with different arrangements of known meteorological station and study point.

There are two objectives in this study, based on the results and discussion from previous chapter, the conclusion for each objective can be made.

5.2.1 Conclusion to Interpolate Wind Speed by using Three Different Interpolation Methods namely IDW, Kriging and Spline

It can be concluded that, all three methods of interpolation have been carried out. Different interpolation methods have different conditions, thus produces different results. However, Kriging method has a limited suitability to be used to estimate wind speed. This is because, it is unable to be executed for study point between two locations. On the other hand, IDW and Spline can be used to estimate wind speed for both types of arrangements of location.

5.2.2 Conclusion to Identify The Best Fit Method to Interpolate for Different Arrangements of Location around Peninsular Malaysia, Singapore and Indonesia

It can be concluded that, Kriging is more suitable when estimating wind speed for a location within an enclosed area. This is due to Kriging method fits a function to a specified number of points within a specific radius. On the other hand, IDW determines cell values using a linear-weighted combination set of sample points, while Spline minimize the total curvature of the surface and passes through the input points. This shows that IDW and Spline are more suitable to be used for study point between two locations.

Therefore, the suitability of different spatial interpolation method used for estimating wind speed is varies for different arrangements of location.

5.3 RECOMMENDATION

For future studies, there are a few recommendations to obtain more accurate results for estimating wind speed by using spatial interpolation. The first recommendation is to collect more wind speed data. In this study, monthly maximum wind speed data and two years of study period were used. Therefore, to obtain more wind speed data, it is recommended to use daily wind speed data and longer study period which is more than two years.

Second recommendation is to have denser sample points. In this study, 10 locations around Peninsular Malaysia, Singapore and Indonesia were used as the area of study. It is recommended to use more locations and locations that are near to each other. This can increase the accuracy of interpolation.

Next, the third recommendation is to have more cases of different arrangements of location. Since the suitability of different interpolation method for estimating wind speed is varies for different arrangements of location, thus a more variety of different arrangements of location can be compared to obtain a more accurate result.

The final recommendation is to compare more different spatial interpolation methods. Different methods have different conditions and produce different results. Therefore, it is recommended to compare more different methods to obtain more accurate results.

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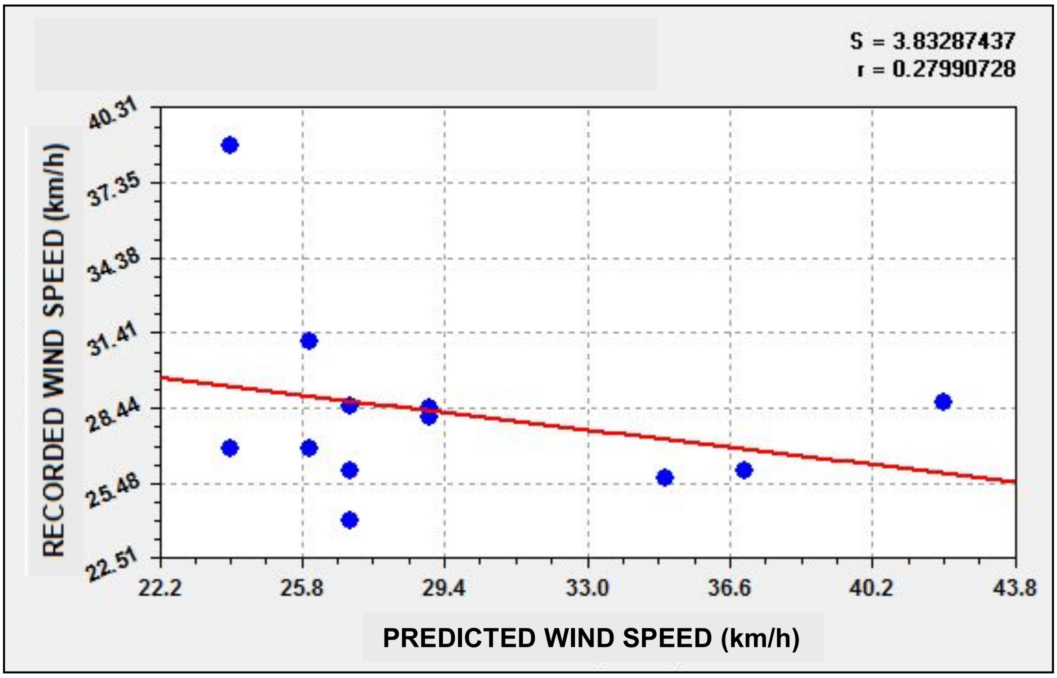
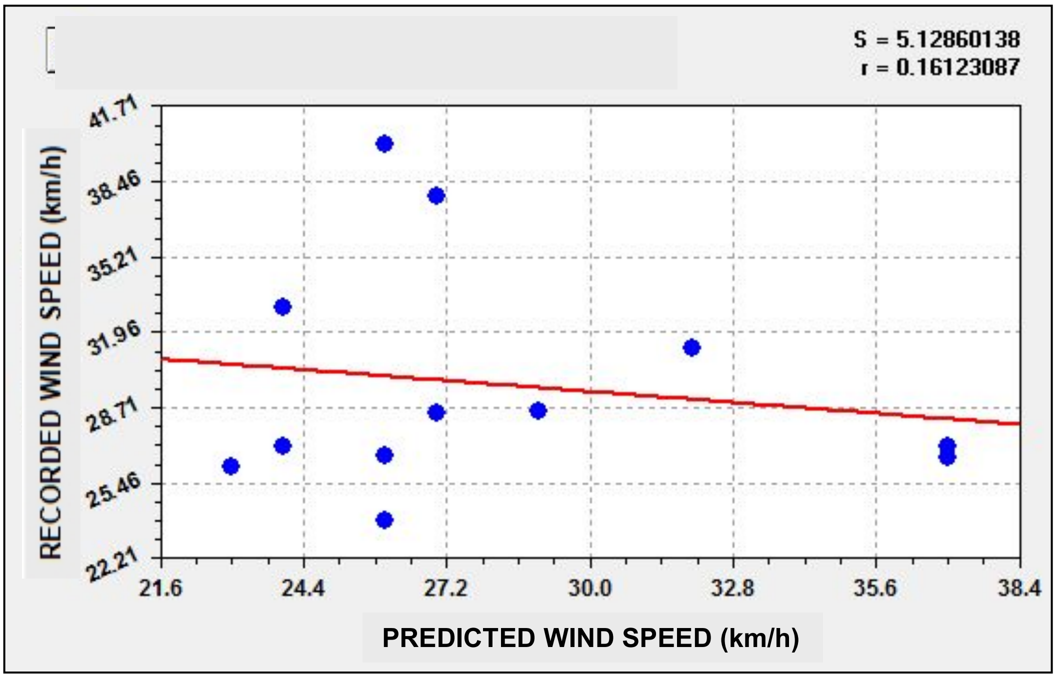
APPENDIX A1
LINEAR REGRESSION GRAPHS FOR CASE 1

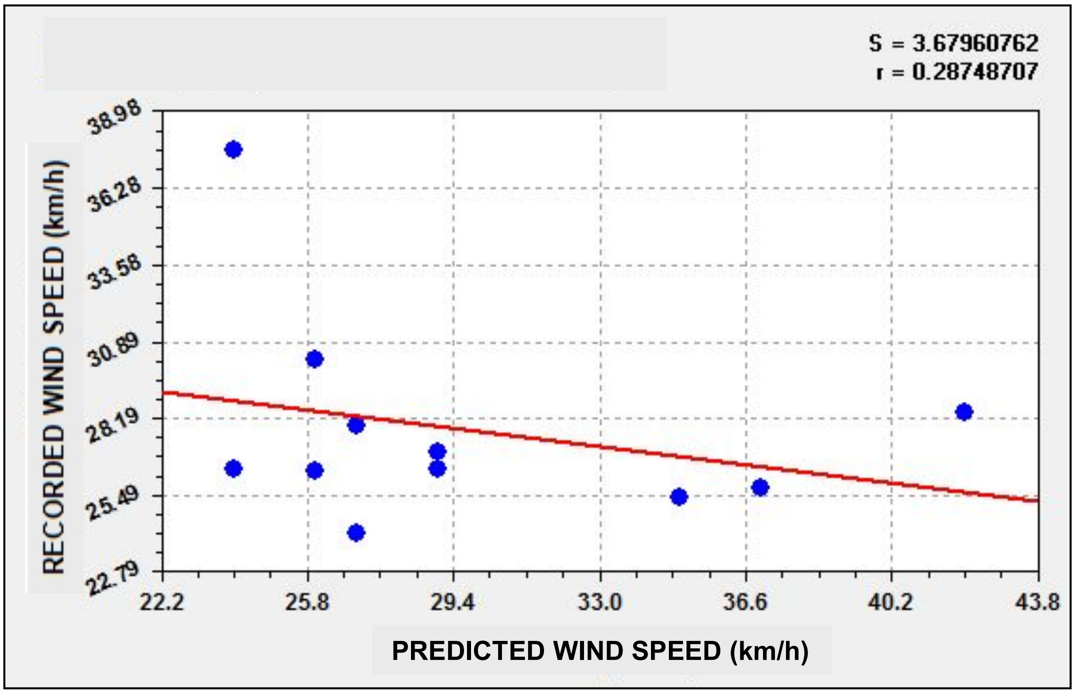
1. IDW (2013)



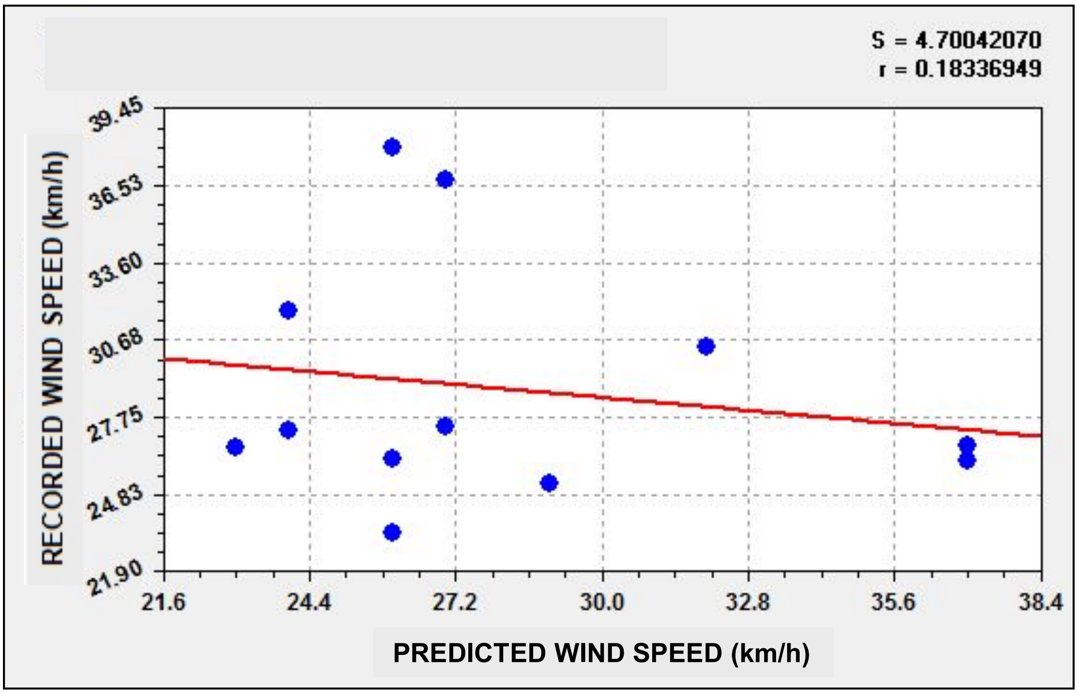
2. IDW (2014)



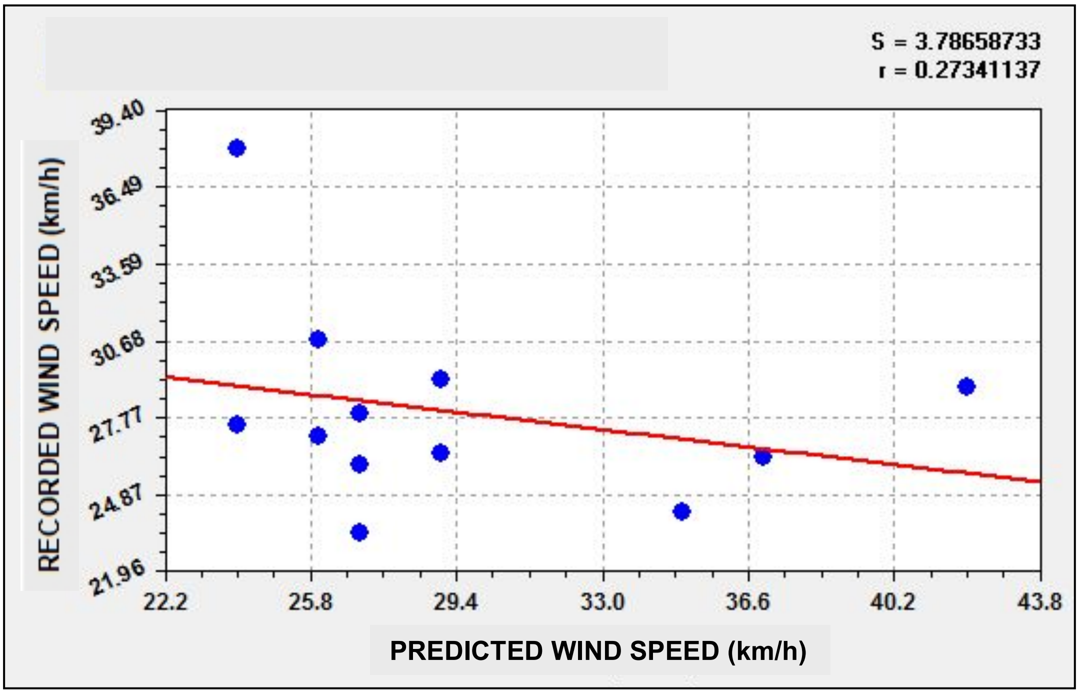
3. KRIGING (2013)



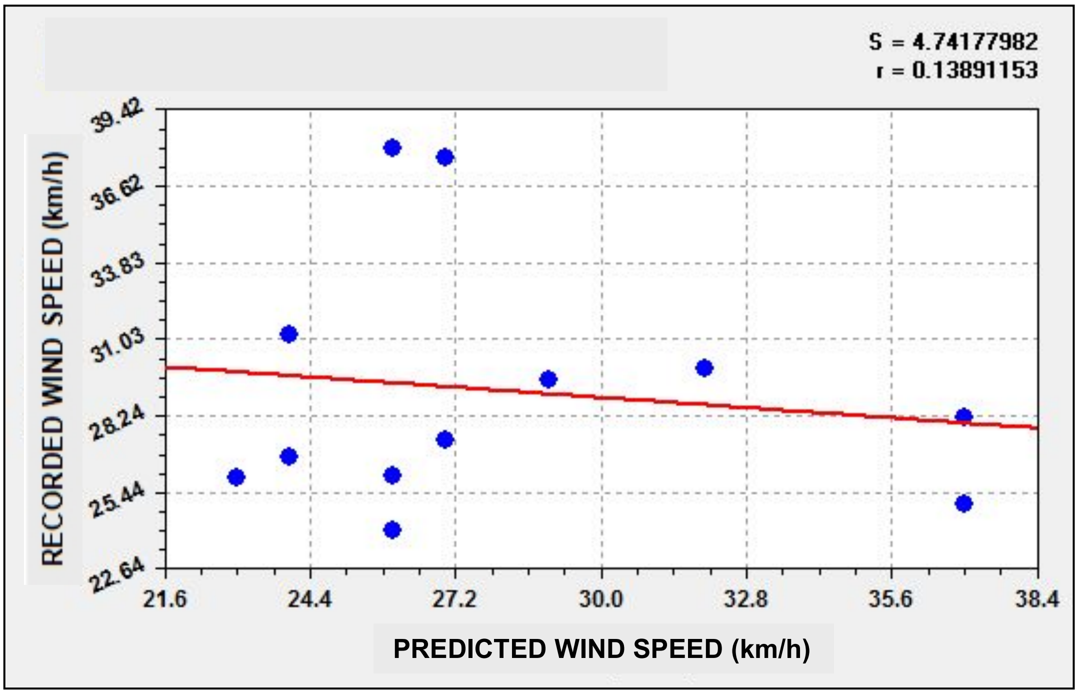
4. KRIGING (2014)



5. SPLINE (2013)

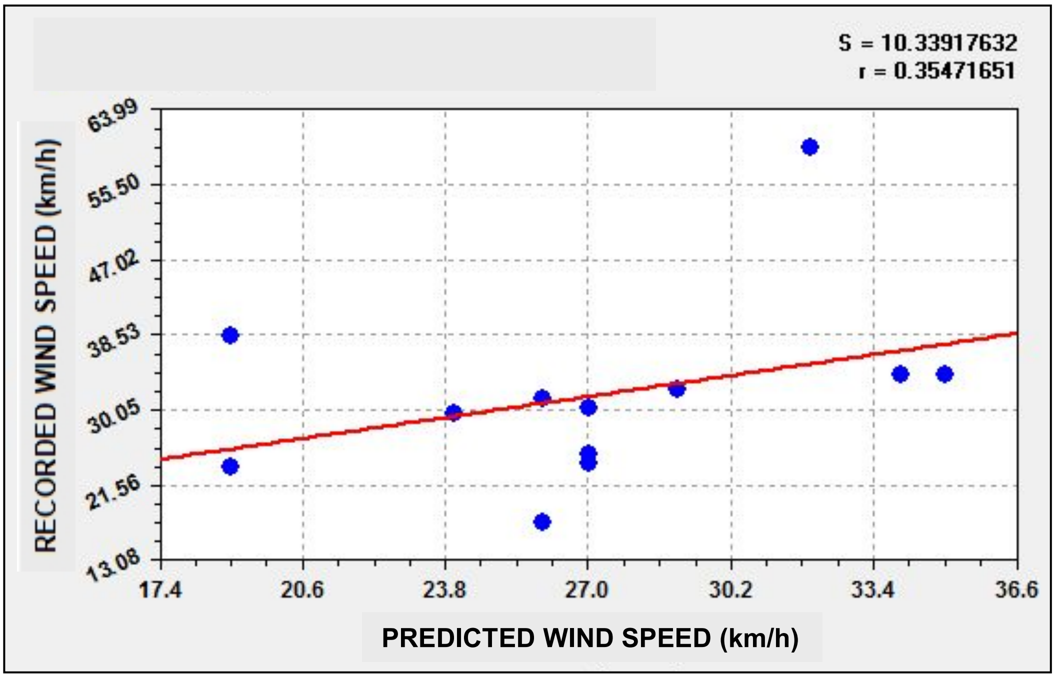


6. SPLINE (2014)

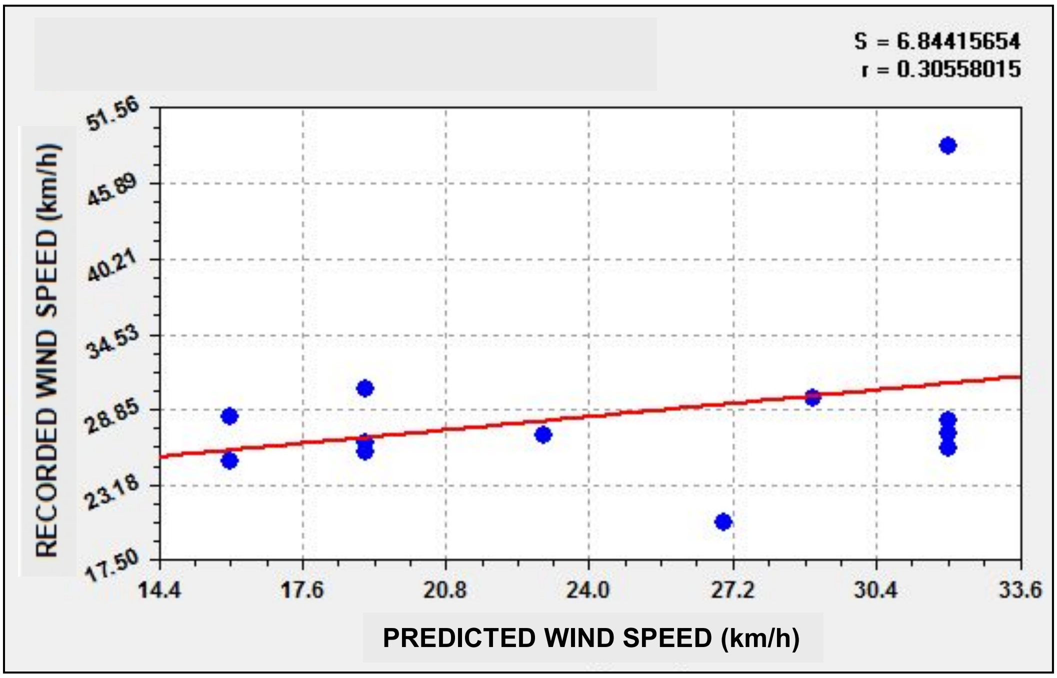


APPENDIX A2
LINEAR REGRESSION GRAPHS FOR CASE 2

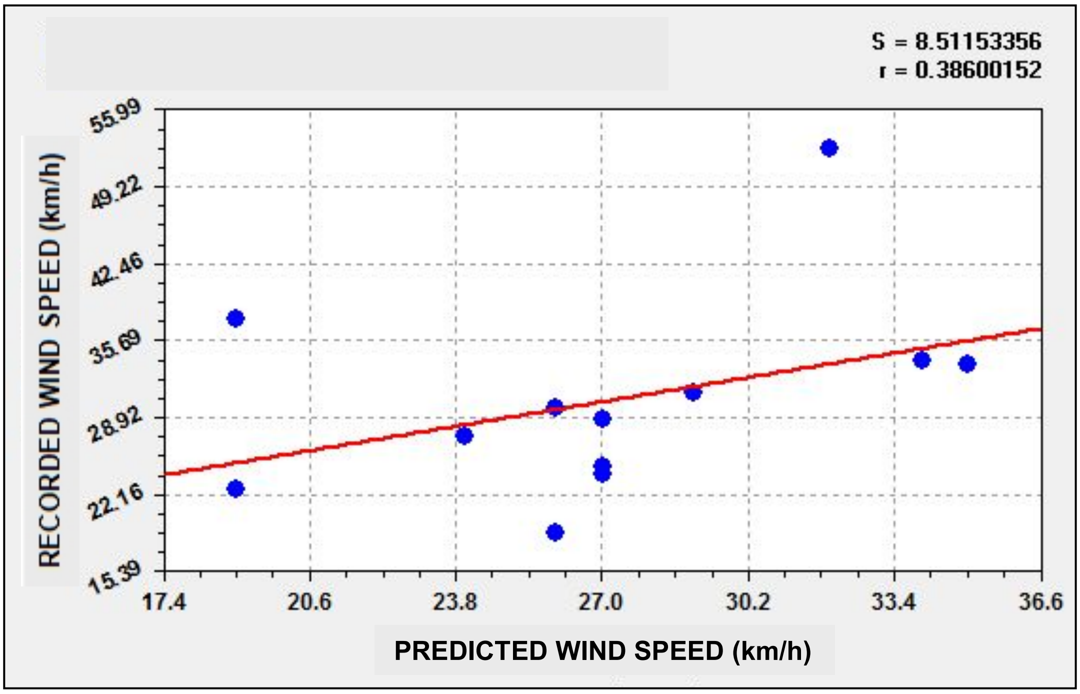
1. IDW (2013)



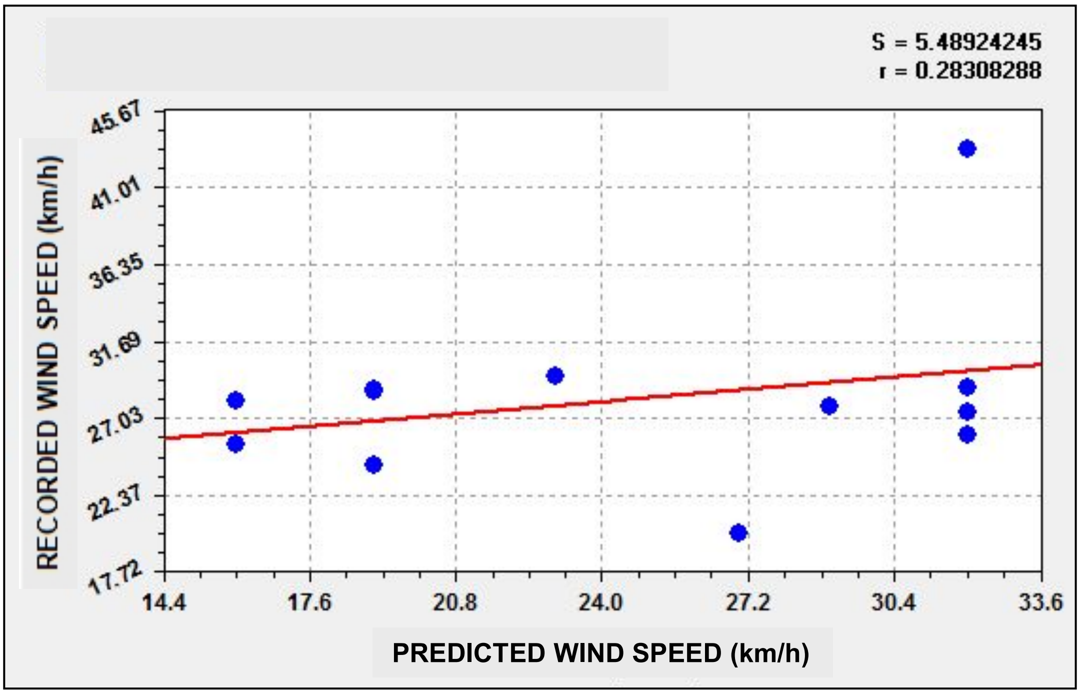
2. IDW (2014)



3. SPLINE (2013)



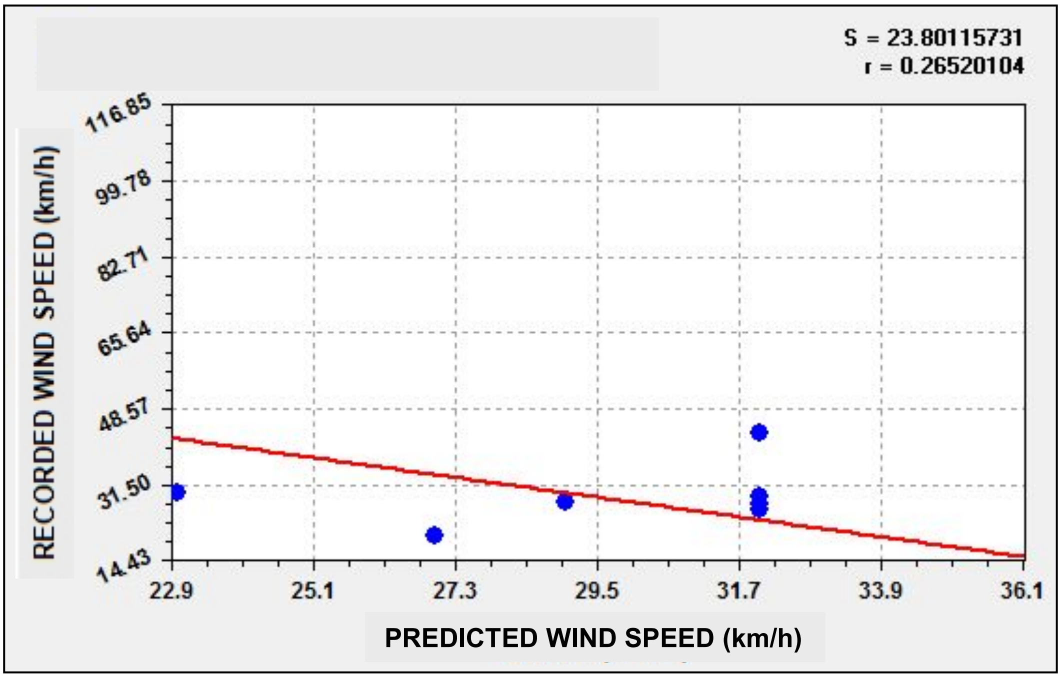
4. SPLINE (2014)



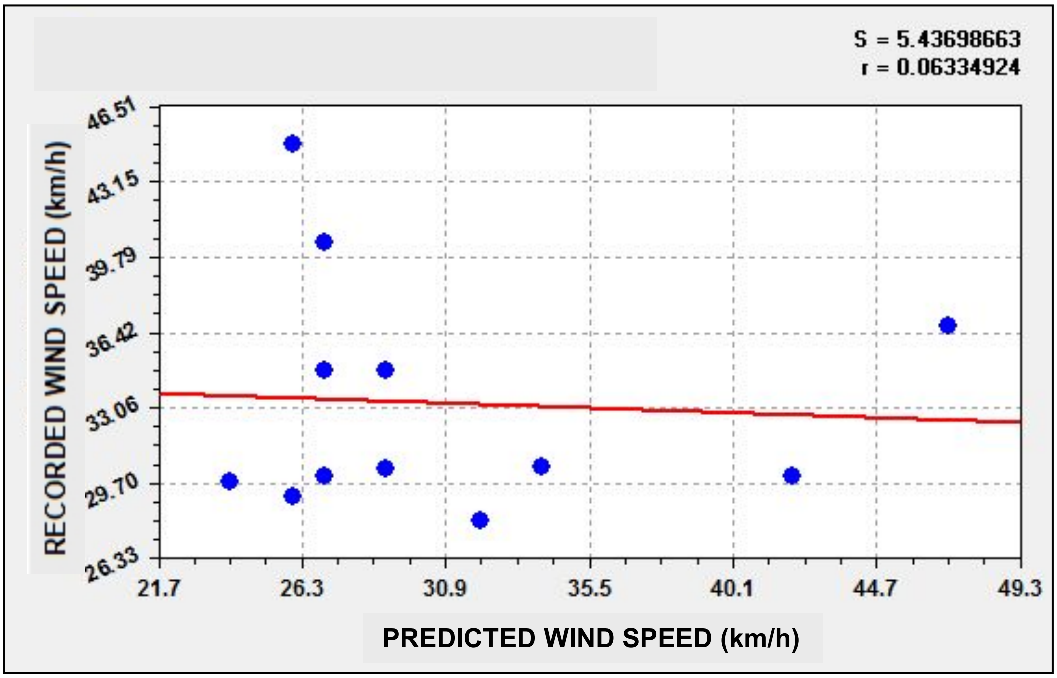
APPENDIX A3

LINEAR REGRESSION GRAPHS FOR CASE 3

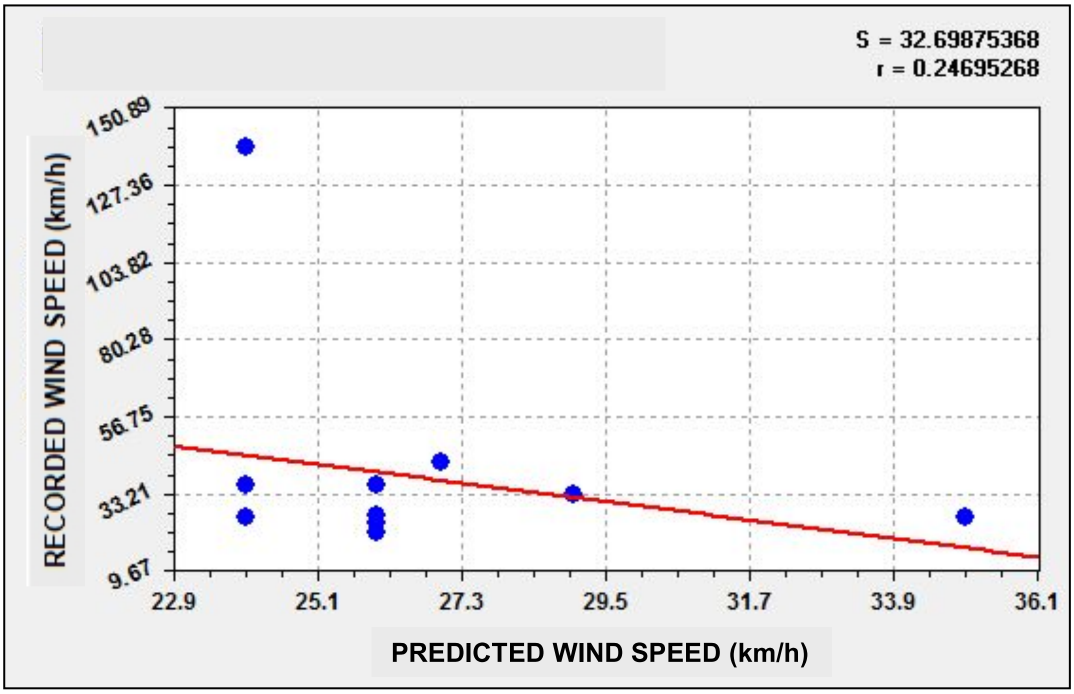
1. IDW (2013)



2. IDW (2014)



3. SPLINE (2013)



4. SPLINE (2014)