

Case Study: Wind Speed Estimation of Wind Storm Damage in Penang Using Surface Interpolation Method and Wind Speed Profiling

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ABSTRACT

The recent freak storm incident in Penang, Malaysia has caused damages to the facilities, uprooted trees and causing death. The aim of this study is to estimate the maximum wind speed at the highest level of a high-rise building that has caused the lightning arrester to drop off and crashed. The wind speed data were collected from four meteorology stations located in Bayan Lepas, Butterworth, Alor Setar and Langkawi. GIS software was used to analyze, estimate and map the wind speed by applying surface interpolation. The interpolation process was conducted by applying the Inverse Distance Weighted (IDW) and Triangulated Irregular Network (TIN) method which are the functions in GIS software namely, IDRISI SELVA. From the plotted wind speed it shows that the result from IDW and TIN are 16.46 m/s and 16.43 m/s respectively. Surface interpolation method was used to estimate the maximum wind speed at 10 m height. By using the power law equation, the estimation of maximum wind speed at Tower A (145.6 m) was conducted and indicates the value of 29.85 m/s and 29.79 m/s. Thus, estimation of maximum wind speed can be approached to determine the value at certain location using these two methods; IDW and TIN and conventional power law method was used to find the value of wind speed at certain height.

Keyword: Wind Speed; Surface Interpolation; GIS; Power Law

1. INTRODUCTION

High-rise or tall building can be defined as a building in which tallness strongly influences planning, design and use and it is not defined according to its height or number of stories.

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Penang has lots of high-rise buildings since it is one of the most developed cities in Malaysia. It is a metropolitan town that is classified as a city with high-rise buildings, industrial and densely populated area, located on the northwest coast of Peninsular Malaysia. Recently, a lighting arrestor situated on one skyscraper in Penang crashed and caused an accident during the freak storm. The main issue in this incident is to estimate the wind speed at that respective level of building at that time. So, the appropriate method to get that value is by using GIS analytical tool.

The difficulty in measuring wind speed on the building is main issue in experimental work (Gross, 1987) since it is difficult and costly to simulate for example wind tunnel experiment. Therefore, the used of GIS analytical tool (IDRISI SELVA) can reduce the cost and time of this study as a solution to address an experimental problem. Spatial interpolation is often an important strategy for creating a continuous surface when taking irregular point data (Kane, 2009).

2. METHODOLOGY

The highest gust data provided by the Malaysian Meteorological Department (MET) has helped in the analytical process using four specific stations situated in the northern state of Malaysia i.e. Bayan Lepas, Butterworth, Alor Setar and Langkawi. Out of three methods used (e.g. Linear Correlation, Beaufort scale, and surface interpolation) only surface interpolation method has given possible value for location at the height of 10 m.

Data collected at four specific stations are required for interpolation process to determine the spaces where point data are not collected (unknown points). Interpolation is the process of estimating the value of unsampled sites within an area covered by the point observations. The rules about the spatial variation and location of data collection points are significant because they can greatly affect the results (Andrews et al., 2002).

The target of interpolation is to capture the local variation of wind speed data using polynomial function model. In this study, the interpolated results of wind speed using GIS IDRISI SELVA software are calculated from four sets of readings simultaneously. The data attribute information contains wind speed. The wind speed data is in the unit of meter per second. The surface interpolation in this study applies two methods i.e. Inverse Distance Weighted (IDW) and Triangulated Irregular Network (TIN).

2.1 Inverse Distance Weighted (IDW)

IDW interpolation is normally used in GIS to produce raster overlays from point data. Once the data are on a regular grid, contour lines can be threaded through the interpolated values and the map can be drawn as either a vector contour map or as a raster-shaded map (Burrough and McDonnell, 1998). This method is based on the extent of similarity of cells and the function is used when the set of points is dense enough to capture the extent of local surface variation needed for analysis (Alamdari et al., 2012).

IDW determine cell values using a linear-weighted combination set of sample points. The weight assigned is a function of the distance, the less influence the cell has on the output value (Childs, 2004). Distance-based weighting methods have been used widely to interpolate climate data. The values that closer to the unsampled location are more representative of the value to be estimated than the samples that further away from this assumption (Luo et al., 2008). The principle of IDW methods is to assign more weight to nearby points than to distant points.

2.2 Triangulated Irregular Network (TIN)

TIN is a vector data structure. The sample data points become the vertices of a set of triangular facets that fully cover the study area. It creates a constrained or non-constrained TIN from isoline or point data. In GIS-IDRISI software, the TIN is generated and then used to create a continuous raster surface model. In addition, the module allows for input of isoline data for TIN creation. In doing so, the TIN can be constrained so no triangular facet edge crosses an isoline. This forces the triangulation to preserve the character of the surface as defined by the isolines (Clarklabs, 2012).

2.3 Power Law

Power Law describes the vertical wind speed profile as a function of height above the ground. Liu (1991) stated the equation of Power Law can be expressed as in Equation 1.

$$V_{(z)} = V_1 \left(\frac{z}{z_1} \right)^\alpha \quad \text{Eq.(1)}$$

Where,

| | | |
|-----------|---|---|
| $V_{(z)}$ | = | Wind speed function of height |
| V_1 | = | Basic wind speed at 10 m height |
| α | = | Power Law exponent |
| z | = | Height above the ground surface |
| z_1 | = | Reference height taken as 10 m above the ground surface |

The power law is frequently used compared to the logarithmic law because the mathematics characteristic in logarithmic law will convey inexistence value of the negative numbers. Therefore, for z which is below the zero displacement will not be able to evaluate. Due to this matter, negative wind speed is obtained (Holmes, 2002). Liu (1991) mentioned that in engineering this law is most often used in engineering application and in code/standard of building because logarithmic law will produce an unreal negative speed at height $z < z_0$.

3. RESULT AND DISCUSSION

Highest gust and direction data are obtained from Malaysian Meteorological Department (MET) station at Bayan Lepas, Butterworth, Alor Setar and Langkawi. Table 1 gives the time, wind direction and highest gust recorded at respective stations.

Table 1: Summary of Wind Speed Data (MET)

| Station | Direction (°) | Highest Gust (m/s) |
|-------------|---------------|--------------------|
| Bayan Lepas | 320 | 19.1 |
| Butterworth | 300 | 15.2 |
| Alor Setar | 190 | 3.0 |
| Langkawi | 270 | 4.0 |

In this study, the interpolated results of wind speed using GIS IDRISI SELVA software are calculated from four sets of readings simultaneously. The data attribute information containing wind speed data in meter per second. During the incident, the wind direction from Bayan Lepas and Butterworth stations were 320° and 300°, respectively (NW direction). It has been anticipated that the wind speed has no significant effect on the KOMTAR building i.e. the highest building in that area as it was not in the wind path of Tower A. Thus, the obstruction from KOMTAR building or other buildings was not considered in this spatial surface interpolation of wind speed mapping.

Figure 1 shows the wind speed map derived from IDW INTERPOL module in GIS IDRISI software. Based on this IDW method the interpolated value of wind speed at Tower A is 16.46 m/s during the event.

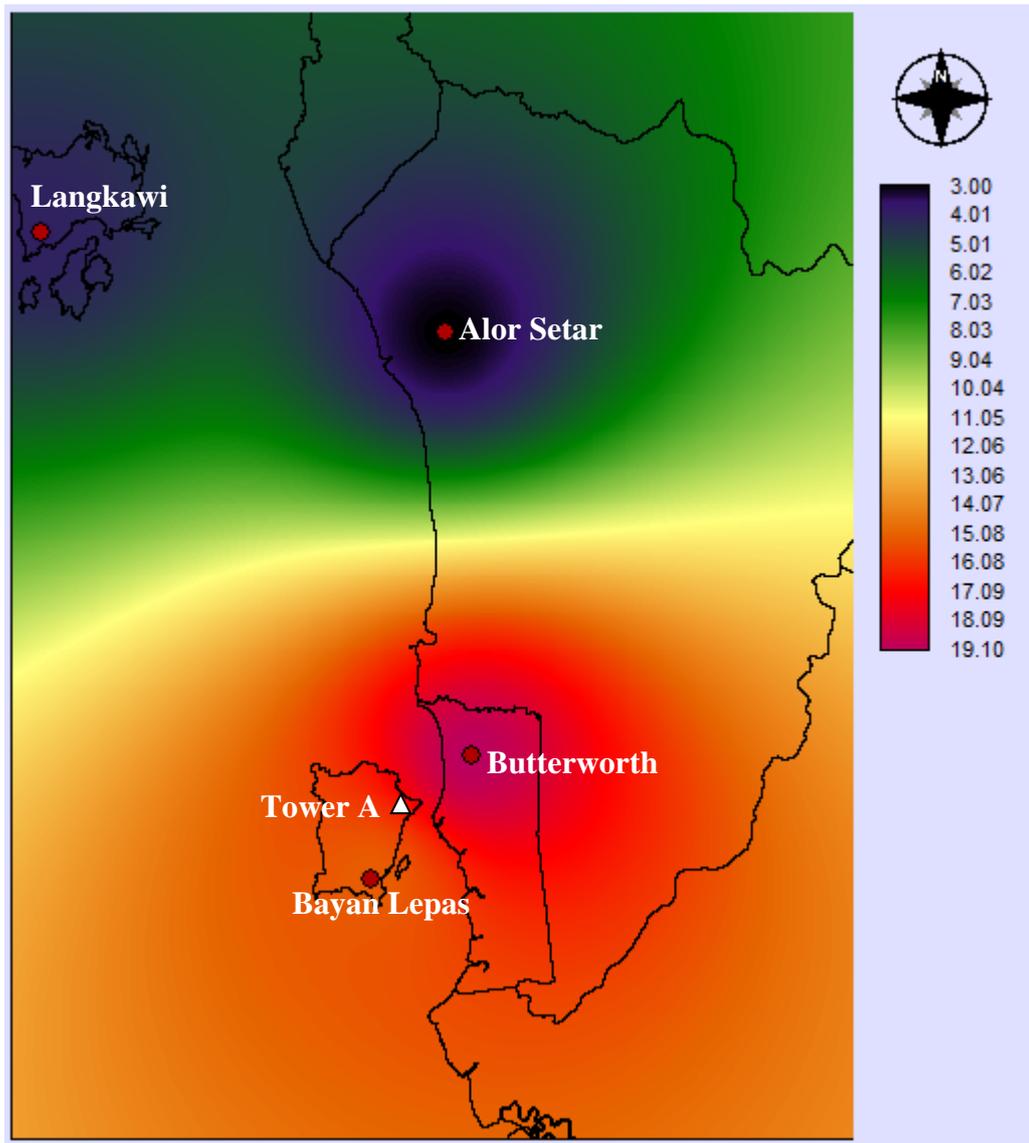


Figure 1: Wind Speed Map using IDW Method

According to Luo et al., (2008), the measured point that is closest to the prediction point will give the best prediction as compared to the furthest point. IDW has the advantage and disadvantage itself. It is simple and quick to calculate but it is easily affected by uneven distributions of observational data and commonly has a 'bird-eyes' pattern around a solitary data point with the values that differ from their surrounding. Luo et al. (2008) has studied the interpolation of wind speed using IDW and found that IDW is consistently adhered to the original wind speed range of the data.

Triangulated Irregular Network (TIN) method as shown in Figure 2 is an alternative method applied to determine interpolated wind speed. It verifies the value of wind speed to be approximately 16.43 m/s as well i.e. same results with IDW method.

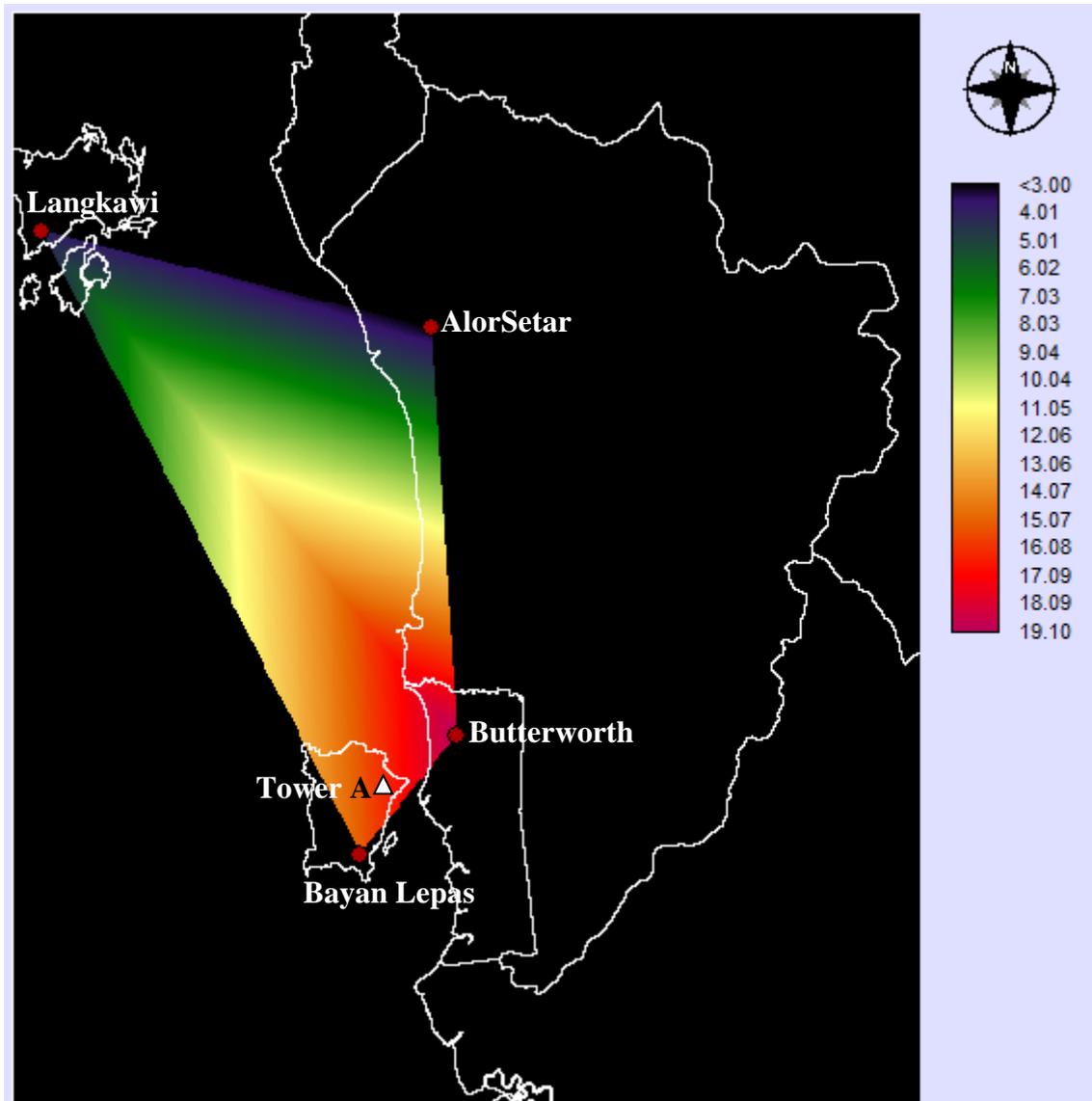


Figure 2: Wind Speed Map using TIN Method

3.1 Vertical Wind Speed Profile

By having the value of tower's wind speed at 10 m height, the power law equation will be the best model equation in representing the vertical wind speed profile for the study area as claimed by most researchers. Power law has been used to estimate the wind speed at the exact height which is 145.6 m tall. According to Malaysian Standard (MS 1553: 2002), Penang island can be classified as terrain Category 4 with terrain of numerous large, high (10.0 m to 30.0 m high) and closely spaced obstruction. So,

Mendis et al. (2007) stated that the roughness for terrain Category 4 (terrain with numerous large, high) is 2.0 meter. Using the power law equation, the estimation maximum wind speed at Tower A (145.6 m) using surface interpolation IDW and TIN is 29.85 m/s and 29.79 m/s respectively. The values for both methods are just slightly different. Using the value of power law result, wind speed profile has been plotted as shown in Figure 3 and Figure 4.

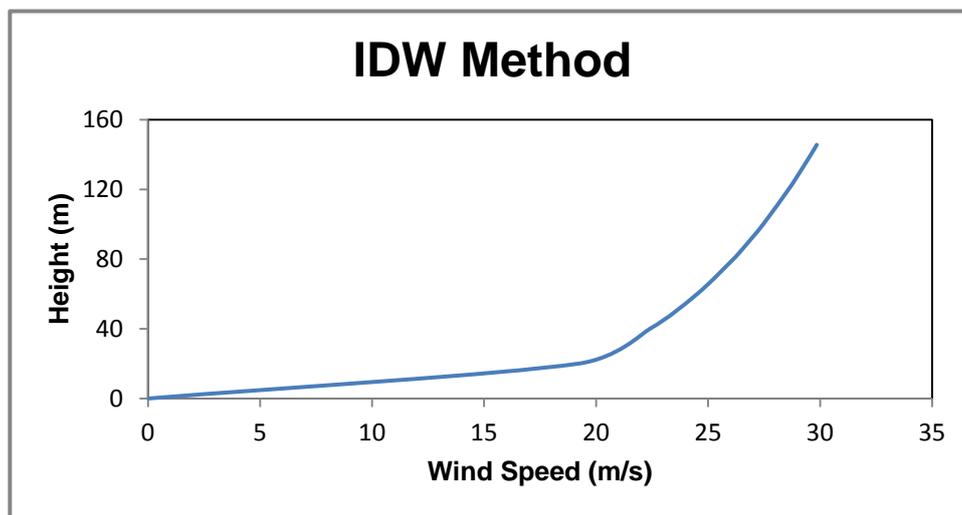


Figure 3: Vertical Wind Speed Profile for Terrain Category 4 (IDW Method)

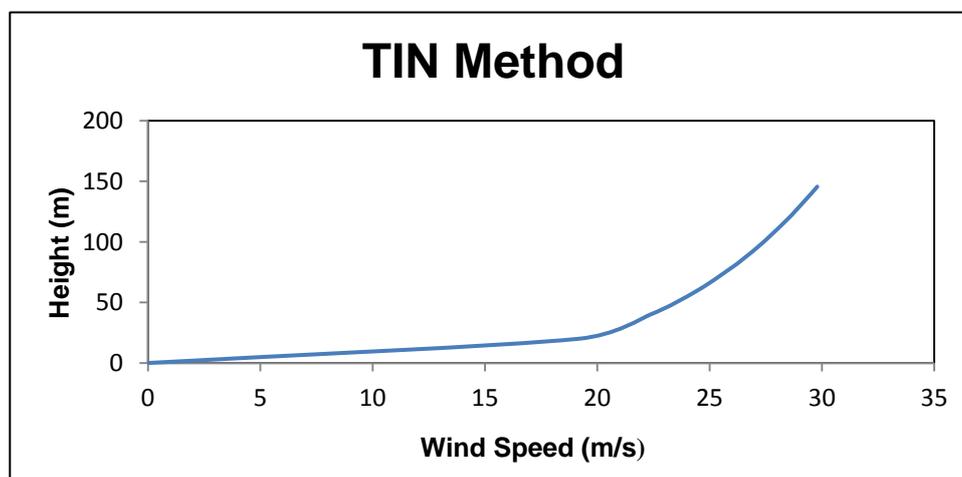


Figure 4: Vertical Wind Speed Profile for Terrain Category 4 (TIN Method)

According to Beaufort scale that was provided by MET, these two results are classified into category violent storm (very rare experienced; accompanied by wide spread damage) with the equivalent speed limit between 28.5 m/s to 32.6 m/s. According to the topography map of Penang Island, this building is surrounded by the hills. Buildings

that are near to the hills will have strong effect that can cause change in direction and wind speed of wind (Liu, 1991).

Liu, 1991 also reported that wind speed will increase quickly at the top of the hills and it is caused due to streamlines. The gradient of wind gets closer to the surface as the height of hills increase, resulting in a reduction of the gradient height of hills. This phenomenon will cause an increase in the speed within the boundary layer. The strong wind may encounter the structures that exist at the leeward of the hills if the direction changes. Stathopoulos, 2007 stated that the turbulence (mechanical) is higher in rougher terrain than in smoother terrain but it will decrease with increasing height above ground.

4. CONCLUSION

Wind speeds and wind directions were obtained at four stations in northern state of Malaysia. This paper discusses on how to estimate the wind speed at certain location and certain height. The estimation of maximum wind speed at unknown location can be determined by using surface interpolation from GIS technique. This method produced wind speed map at northern region of Malaysia. Power law is another possible method to estimate the wind speed at that location at the tip of arrestor (145.6 m) after GIS technique found the wind speed at 10 m by plotting the vertical wind speed profile. From GIS technique, there two methods has been applied which are IDW and TIN method that gave almost the same result which is 16.46 m/s and 16.43 m/s. From these two results, the vertical wind profile has been plotted and gave the value of 29.85 m/s and 29.79 m/s and can be categorized as violent storm.

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