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Case Study: Wind Speed Estimation of High-Rise Building Using Surface Interpolation Methods

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Abstract This paper is based on the event in Penang that caused fatality, injuries and damages. This study focuses on high-rise building near to the incident area using the wind speed during that event. The aim of this study is to compare the best interpolation methods from the results of estimated wind speed at that respective building. The interpolation process used IDW and TIN method using GIS IDRISI Selva software. IDW method covers for all the area but TIN method do not cover beyond the triangulation point. The value of wind speed is 17.46 m/s for both IDW and TIN method but the most preferable method is IDW. The value of wind speed can be higher or lower than the estimation value if the factors that can change the value of wind speed had been considered in the mapping.

Keywords Surface Interpolation, GIS, Wind Speed

1. Introduction

Windstorm is one of natural disaster happen in our country besides epidemics, floods, earthquakes, mass movement dry and mass movement wet. According to CRED [1], 21.19% of natural disaster in Malaysia related to storm. This number is not a small number but it is something to be aware and worry not only by the government but also individual itself. The common damages caused by windstorm are uprooted trees and blown off roofs. Penang state can be classified as a sub-urban area with a lot of high-rise buildings. There were too many incident related to windstorm and high-rise building. One of the incidence happened in Penang in 2013 that caused damages, injuries and fatal. This study focuses on the high-rise building near to the location of incident using the data during the incident provided by MET. Ramli et al. [2] reported that average of wind speed will increase as the height increase and force acting on structures depends on terrain category [3]. Liu [4] stated that, building or structures deflect winds, causing a change in wind speed and direction around the buildings or structures. Frictional effects show an important role for wind near the ground surface. Thus, the mean wind speed may change in direction slightly with height, as well as magnitude [5]. As stated in MET [6] report, the general features of the climate in Malaysia are uniform temperature, high humidity, copious rainfall and light wind. It also reported that the southwest monsoon season usually happened in the late half of May or early June and in September. Wind climate in Malaysia is conquered by two monsoon seasons and inter-monsoon thunderstorms Majid et al. [7].

The estimation value of the wind speed at that building was determined using surface interpolation method available in GIS software tools (IDRISI Selva). IDRISI Selva is one of the GIS software that commonly used in mapping the wind speed other than ArcGIS.

Spatial interpolation is the process of calculating an unknown at the specific point using a set of sample point with known values that are distributed across the area. The rules about the spatial variation and location of data collection points are important because they can significantly affect the results [9]. Apaydin et al. [8] stated that spatial interpolation has its own special which can be used to estimate meteorological variable at other location. The aim of this study is to compare the best result using two surface interpolation methods from the results of estimated wind speed at the respective building at the height of 10 m from ground surface.

2. Methods

2.1. Datasets

The map was interpolated by using the datasets that provided by Malaysian Meteorological Department (MET) on the same date and time as the incident happened. The minimum numbers of point to be interpolated are four points which are Alor Setar, Langkawi, Butterworth and Bayan Lepas. The selected points based on the closer distance from the location of incident. There are two methods that have been used in this study which are Inverse Distance Weighted

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(IDW) and Triangulated Irregular Network (TIN). Both methods are used for surface interpolation purposes. Spatial interpolation is often an important strategy for creating a continuous surface when taking irregular point data [10]. Apaydin et al. [8] stated that the interpolation techniques were group into two main categories which are deterministic and geostatistical and IDW are categorized as deterministic because this technique create surface from measured points, based on either extent of similarity.

2.2. Inverse Distance Weighted (IDW)

IDW interpolation is commonly used in GIS to create 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 [11]. Luo [12] and Chinta [13] has quoted the paper from Theissen [14] and stated that IDW interpolation combines the idea of proximity espoused. The IDW function is used when the set of points is dense enough to capture the extent of local surface variation needed for analysis; therefore, it was used in this study [15]. The principle of IDW methods is to assign more weight to nearby points than to distant points.

The usual expression is,

$$\mathbf{Z}(s_0) = \sum_{i=1}^{n} \lambda_i . \hat{\mathrm{Z}}(s_i) \quad (1)$$

where,

$\boldsymbol{Z}(s_0)$ = the value to be predicted for location s □

$\boldsymbol{n}$ = the number of measured sample points surrounding the prediction location that will be used in the prediction

λ_i = the weights assigned to each measured point to be used

$\hat{\boldsymbol{Z}}(s_i)$ = the observed value at location si

2.3. Triangulated Irregular Network (TIN)

TIN is another tool in GIS and it is a vector data structure. It creates a surface formed by triangles of nearest points. The sample data points become the vertices of a set of triangular facets that completely cover the study area. In IDRISI, the TIN is generated and then used to create a continuous raster surface model. TIN creates a constrained or non-constrained TIN from isoline or point data. In TIN method, there are two principal phases to be generated which are the selection of the point data and connection into triangular facets [16]. In this study, the IDRISI TIN module is created from the input of isoline data from fours stations in Northern region of Peninsular Malaysia. 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 [17].

3. Result and Discussion

The interpolated results of wind speed using GIS IDRISI Selva software is calculated from four sets of reading during the event and at the same time. The data attribute information contains wind speed and wind direction. The wind speed data is in the unit of meter per second while the wind direction data is in unit of degree. Table 1 shows the maximum wind speed during that event for each station.

Table 1. Summary of Wind Speed Data (MET)

Station	Wind Direction (°)	Maximum Surface Wind (m/s)
Butterworth	300	19.1
Bayan Lepas	320	15.9
Alor Setar	210	14.0
Langkawi	270	14.9

The data from Table 1shows that the highest wind speeds during the incident is 19.1 m/s at Butterworth station. Since the reading at respective high-rise building cannot be collected during the incident, the surface interpolation method has been applied by using GIS IDRISI Selva tools. For this study, only two techniques are applied to find the compatible and applicable methods. The red points in Figure 1 and 2 describe the location of the station which is in Bayan Lepas, Butterworth, Alor Setar and Langkawi while the white triangle shape shows the location of the respective high-rise building (Building A). The interpolated value of wind speed of the building at 10 m height is approximately 17.46 m/s during the event as shown in Figure 1. Triangulated Irregular Network (TIN) method as shown in Figure 2 is the alternative method applied to determine interpolated wind speed. It verifies the value of wind speed to be approximately 17.46 m/s as well i.e. same results with IDW method. Based on Beaufort scale, the value of this wind speed for both methods can be categorized as fresh gale.

Liu [4] stated in his book that many factors may slow down the wind in certain regions, shielding or accelerate such as topography, woods, buildings and other structures and are be able to change the speed or direction of the wind. Besides that, when turbulent flows from a different surface layer to another surface layer, the wind flow may accelerates or decelerates depending to the change of surface roughness. The rougher the terrain is, the more it retards the wind speed.

This study interpolates the wind speed without considering other factors that may change the direction or speed of wind. The estimation value of wind speed at respective building can be higher or lower than the exact value. As stated in the book of Liu [4] that topography and structures are one of the factors that may change the wind speed and direction, this building absolutely affected by this factor since it is surrounded by the hills and highest building that are more than 10 m.

The interpolation using TIN method is not smooth as IDW method because of discontinuous slope at the triangle edges and it is not suitable for extrapolation beyond the area with the set of sample point. Fortunately, in this study, the respective location (Building A) falls within interpolation area using TIN method but the IDW method covers all the area.

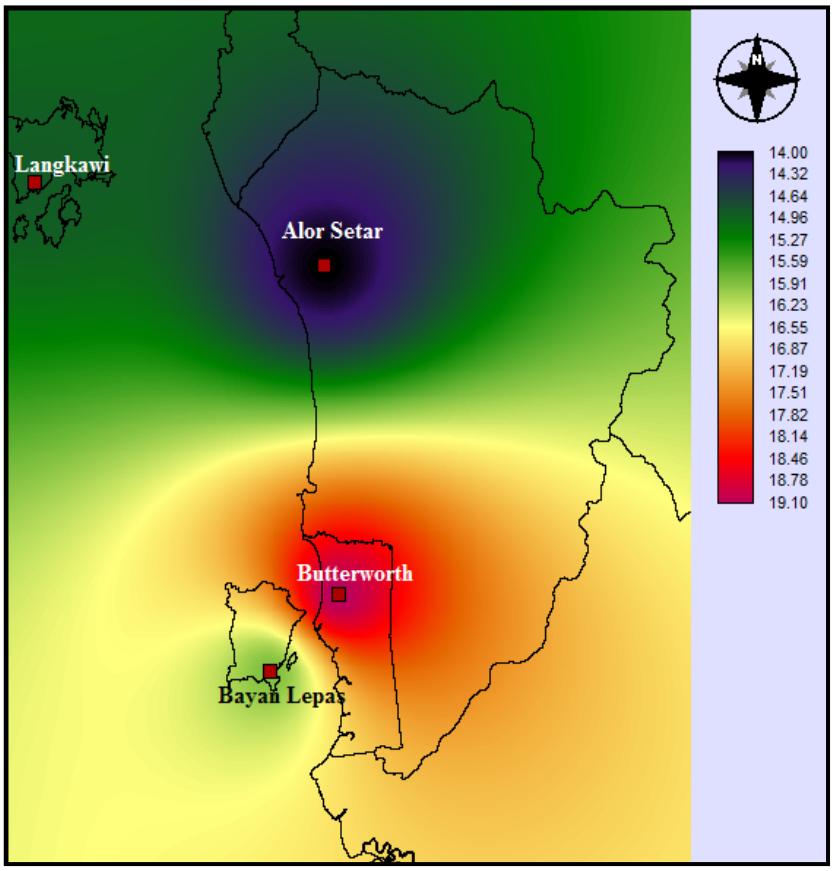

Figure 1. Wind Speed Map using IDW Method

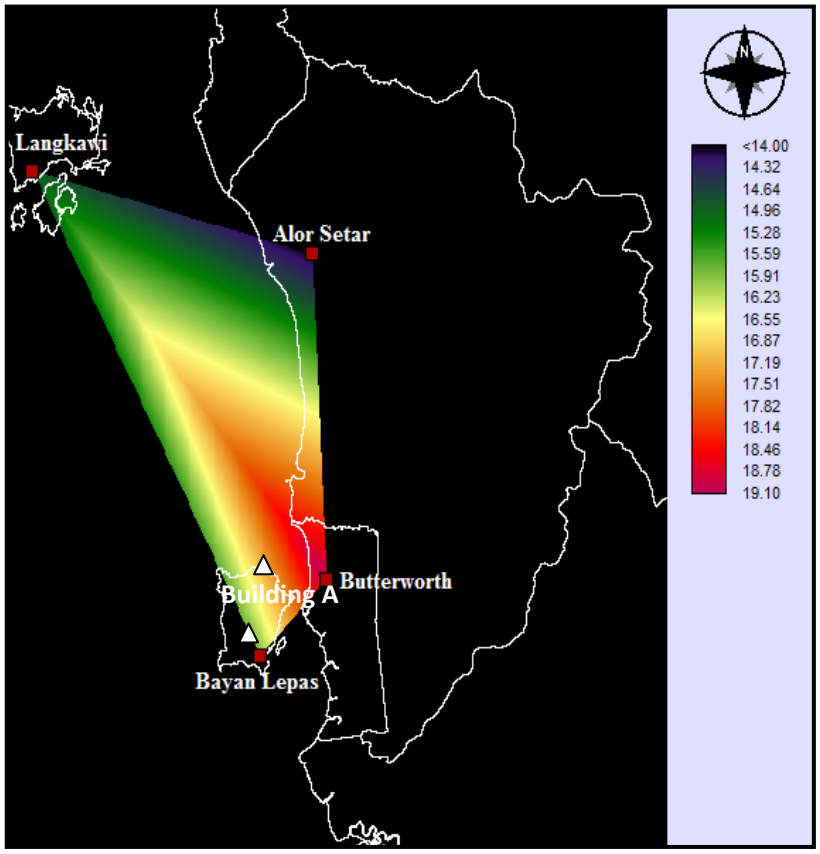

Figure 2. Wind Speed Map using TIN method

4. Conclusions

The result from IDW and TIN method give the same value of wind speed which is 17.46 m/s at the height of 10 m from ground surface. This value is not the worst that can cause the structure collapsed. It may caused by the failure of the structure itself. The use of surface interpolation is to predict the value at specific location and the most preferable method to be applied is IDW because it can be used for interpolation and extrapolation. Morever, to get the accurate value of wind speed at that building, the factors that will affected the wind speed must be considered before doing interpolation process.

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