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A wind hazard study using the spatial modelling approach

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A wind hazard study using the spatial modelling approach

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Abstract. Wind Hazard such as a tornado outbreak may lead to a serious threat especially in damaging properties. Tornado is rarely reported in Malaysia which makes the early assumption of 2014 occurrence is due to the cumulonimbus cloud formation process which was further intensified by the wind factors of the monsoons season. This study attempted to determine the spatial correlation between strong winds occurrence in relation to the wind characteristics during the tornado outbreak in Pendang district of Kedah. The GIS process was performed to determine the most likely wind speed and wind direction on that particular date and place which will further enhance the understanding of such phenomena. This study which was carried out based on the data obtained from the Meteorological Department of Malaysia produced a significant discussion that must be considered in future research.

1. Introduction

Wind or simply moving air is caused by air flowing from an area of high pressure to an area of low pressure and generally described by its direction and speed. Likewise, the air pressure is the amount of force the molecules exert on a given area. When the area is warm, the molecule rises and creates a low pressure environment. In reaching the equilibrium air pressure, the area of higher air pressure will moves to the lower air pressure, thus create winds. Strong winds are due to a strong pressure gradient force. A pressure gradient is the rate of change of pressure over a certain distances. For example, when pressure changes rapidly over a small distance, the pressure gradient force is large which will create a strong wind. Strong winds almost always result from large pressure gradient [1]. Strong winds are the most common means of destruction associated with hurricanes that sometimes can uproot trees, knock over buildings and homes [2]. In Malaysia, the characteristic features of the climate are uniform temperature, high humidity, and copious rainfall [3]. Though the wind over the country is generally light and variable, there are, however, some uniform periodic changes in the wind flow patterns. Based on these changes, four seasons can be distinguished, namely, the southwest monsoon, northeast monsoon and two shorter periods of inter-monsoon seasons [4]. The southwest monsoon season is usually established in the latter half of May or early June and ends in September [5]. The prevailing wind flow is generally south-westerly and light, below 8 m/s. The northeast monsoon season usually commences in early November and ends in March. During this season, steady easterly or north-easterly winds of 5 to 10 m/s prevail. The winds over the East Coast states of Peninsular Malaysia may reach 15.5 m/s or more during the strong surges of cold air from the north (cold surges) [6]. During the two inter-monsoon seasons, the equatorial trough (continuous belt of low atmospheric pressure) lies over Malaysia.

Wind data are generally recorded at point locations i.e. meteorology stations. Therefore, estimating wind data at specific locations requires some form of spatial interpolation since there are limited

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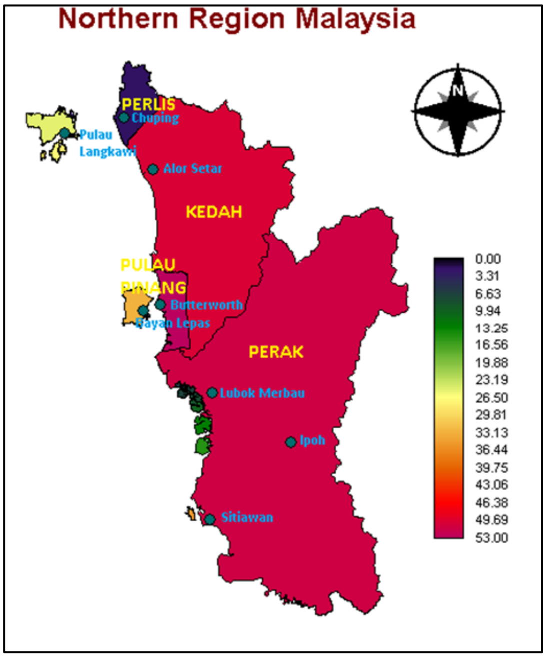
number of meteorological stations throughout Malaysia. Geographical Information System (GIS) spatial modelling approach can be used to estimate wind speed and direction of a specific location where the observation station were not available. In this study, the GIS Inverse Distance Weighting (IDW) spatial interpolation model was used to interpolate the continuous wind speed and wind direction on specific date of strong wind occurrence in northern region Malaysia. The study was carried out within the period of September 2016 to June 2017. The case study investigates the historical strong wind occurrence which happened in Pendang, Kedah on 14th October 2014. The interpolated area were based on the meteorological stations in four northern region states of Malaysia – Perlis, Kedah, Pulau Pinang and Perak.

2. The Historic Case of Tornado Occurrence

The strong wind occurrence in Pendang, Kedah on the October 2014 as shown in Figure 1 was apparently due to the cumulonimbus cloud formation process which cause the instability of the atmosphere in the transition of monsoon winds. As the monsoon winds changes, the atmosphere is unstable and formations of the clouds easily appear. The strong winds blew off the roofs of some houses in a village, while many trees were uprooted. Luckily, this tornado incident does not result in loss of lives [7].

Figure 1. Tornado in Pendang, Kedah on 14 October 2014 [14]

The study is intended to determine whether strong winds occurrence is spatially correlated with the wind speed and direction. Since the daily wind data of a specific location can be interpolated and modelled through spatial interpolation processes. In addition, this project also attempts to determine the spatial relationship of periodic wind data and the effectiveness of spatial interpolation algorithm namely the Inversed Distance Weighted (IDW) in wind study. Hence, the objectives of the study is namely to analyse the raw data on wind speed and wind direction from eight (8) meteorological stations in the northern region of Peninsular Malaysia (Figure 2).



Station	Lat.	Long.	Elev.
AlorSetar	6° 12’ N	100° 24’ E	3.9 m
Bayan Lepas	5° 18’ N	100° 16’ E	2.5 m
Butterworth	5° 27’ N	100° 23’ E	3.3 m
Chuping	6° 29’ N	100° 16’ E	21.7 m
Ipoh	4° 34’ N	101° 06’ E	40.1 m
Lubok Merbau	4° 48’ N	100° 54’ E	77.5 m
Pulau Langkawi	6° 20’ N	99° 44’ E	6.4 m
Sitiawan	4° 13’ N	100° 42’ E	6.8 m

Figure 2. The Spatial Characteristics of the Meteorological Stations

The hourly wind speed and wind direction from the respective meteorological stations were obtained on four successive dates, before and after the tornado event (Table 1). It was statistically analysed to determine the average daily wind speed and wind direction. Subsequently, the spatial interpolation algorithm using IDW derives the average wind speed and direction maps over the particular period. Lastly, the spatial correlation analysis was performed to determine the relationship of the generated wind speed and direction map with the tornado occurrence.

Table 1: Wind speed and wind direction before, during and after the tornado occurrence [6]

DATE	1 OCTOBER 2014		14 OCTOBER 2014		15 OCTOBER 2014		31 OCTOBER 2014	
STATION	Speed (m/s)	Direction (°)	Speed (m/s)	Direction (°)	Speed (m/s)	Direction (°)	Speed (m/s)	Direction (°)
ALOR SETAR	0.77	274	0.66	58	0.27	14	0.50	358
BAYAN LEPAS	0.09	4	0.31	245	0.15	2	0.88	332
BUTTERWORTH	0.51	1	1.08	94	0.77	102	0.82	352
CHUPING	0.54	320	1.17	11	0.93	45	0.52	23
IPOH	1.21	41	0.55	66	0.66	27	0.54	78
LUBOK MERBAU	0.27	5	0.12	223	0.44	148	0.72	250
PULAU LANGKAWI	0.41	44	0.77	72	0.44	104	0.11	59
SITIAWAN	0.34	343	0.13	166	0.26	140	1.00	296

3. Methodology

3.1 Inverse distance weighted (IDW) spatial interpolation model

One of the most frequently used deterministic models in spatial interpolation is the inverse distance weighting (IDW) method [8]. It is relatively fast and easy to compute, and straightforward to interpret. Its general understanding is based on the assumption that the attribute value of an unsampled point is the weighted average of known values within the neighbourhood, and the weights are inversely related to the distances between the prediction location and the sampled locations. IDW is used to estimate cell values by averaging the values of sample data points in the neighbourhood of each processing cell [9]. The weight of each sample is inversely proportional to the distance which means the further away the point from the unsampled point, the less the weight in helping to know the values. The interpolation equation [10] is as shown below:-

$$Z_j = \frac{\sum_i \frac{Z_i}{d^n ij}}{\sum_i \frac{1}{d^n ij}} \tag{1.0}$$

Where, Z_j is the unknown wind speed value, Z_i is the known wind speed, n is a user selected exponent (default value of 2) and d_{ij} is distance of unknown wind speed point and known point.

The inverse distance weight is modified by a constant power or a distance decay parameter to adjust the diminishing strength in a relationship with increasing distance [8]. 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 [11]. The principle of IDW methods is to assign more weight to nearby points than to distant points, thus the more sample points with good spread throughout the study area the better. Luo et al [11] added that they have studied the interpolation of wind speed using IDW and found that IDW consistently adheres to the original wind speed range of the data.

3.2 Analyzing the wind speed and wind direction

The mean wind speed was determined using the Microsoft Excel. The average wind speed is simply the scalar average of the wind speed observations. However, for wind direction, the “unit-vector" average was used to calculate the average wind direction. In this technique, unity serves as the length of the vector, and the wind direction observations serve as the orientation of the vector, and the *u* and *v* components are then calculated for each observation [12]. Subsequently, the average *u* and *v* components were computed and the average wind direction derived using formula "*arctan (u/v)*".

3.3 Data preparation in GIS

The Pendang district map, as well as the other towns map obtained from the Google Map, were resampled to the Malaysian plane coordinates. The end results were georeferenced maps that can be overlaid with the other map describing the location of the 8 meteorological stations in the northern region. The input average wind speed and wind direction were assigned to the respective stations over the various date of data being collected. This enable the interpolation of continuous to be performed.

3.4 Spatial interpolation for continuous wind data

The spatial interpolation estimates the unknown values of wind data within the study area. The IDW algorithm estimate cell values by averaging the values of sample data points in the neighbourhood of each processed cell [13]. The weight of each sample is inversely proportional to the distance which means that the further the points from the unsampled point, the less the weight was assigned to the values.

3.5 The magnitude and direction of wind map

The magnitude and direction of the wind was created using the vector field plot tool (*VField*) in IDRISI GIS-Software. A vector field plot consists of a two-dimensional array of vectors (arrows) that represent the magnitude and direction of a force. Storing information about the flow of wind as vectors provides flexibility in calculating wind direction. Generally, meteorologists uses arrows or another special symbol to show the direction from which the wind is blowing. The head of the arrow points in the direction from which the wind is blowing. Figure 3 provides the interpretation of the wind speed direction and its magnitude on the GIS map.

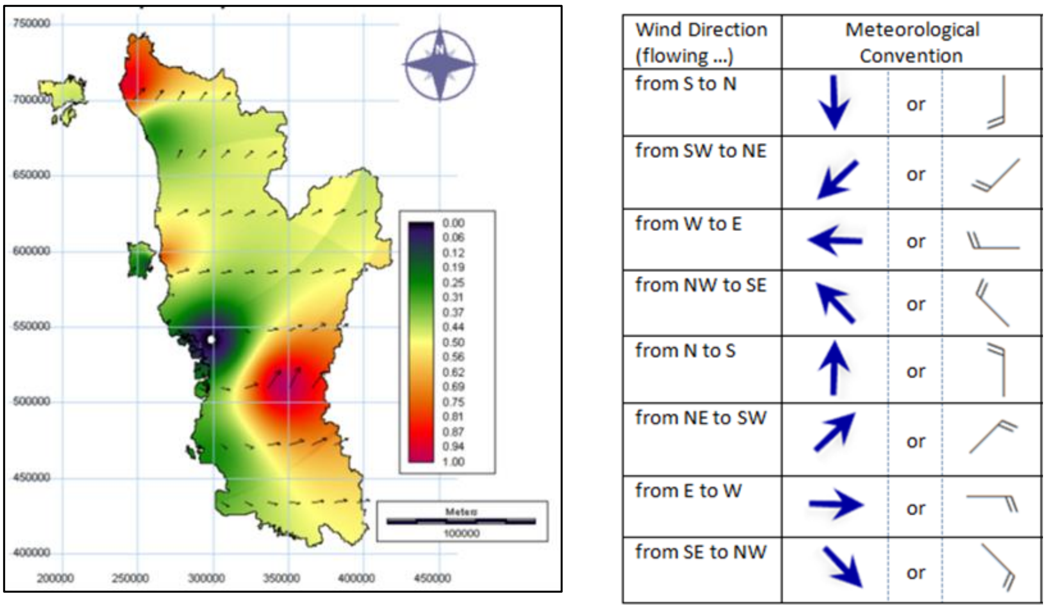


Figure 3. Example of Magnitude and Direction Map

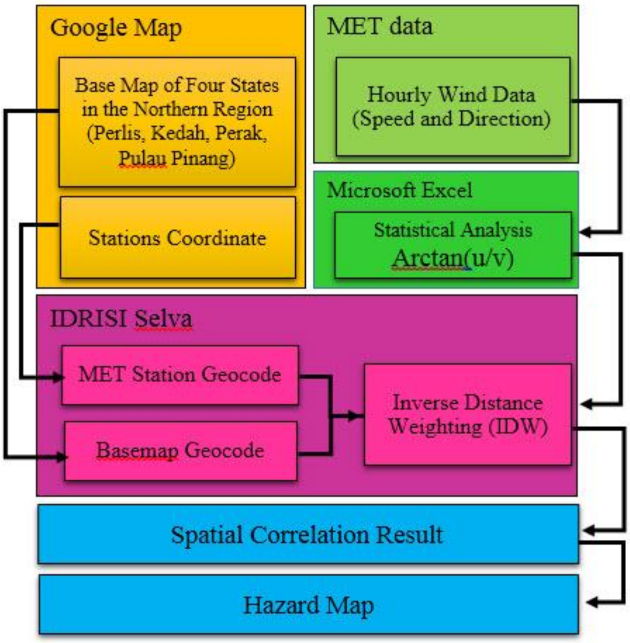


Figure 4. Flowchart of Methodology

4. Results and discussions

The results are presented in two forms; graph (Figure 5) and wind map (Figure 6). The graph shows the average wind speed in the duration of 4 days in the month of October 2014 based on 8 meteorological stations throughout northern region.

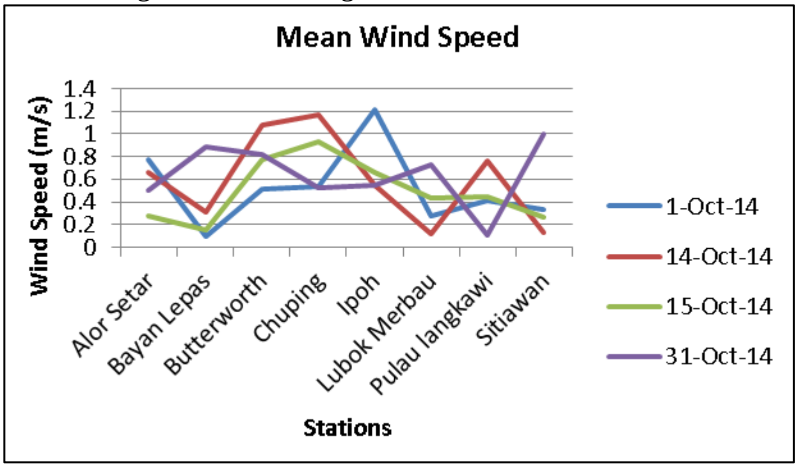


Figure 5. Graph of average wind speed by stations

For the discussion, only the interpolated results on the 14th October is highlighted here, as it represents the date of the tordano occurrence in Pendang, Kedah (Figure 5). The interpolation from the average wind speed at Chuping station was 1.17 m/s that surpassed the recorded wind speed value at Butterworth (1.08 m/s). In addition, Figure 6 shows that the wind was blowing in the North-East direction at Chuping then changed its direction to East-South at Butterworth station. However, nearest to Pendang district was the Alor Setar meteorological station that recorded the average wind speed value of 0.66 m/s. It did not represent with the wind force that can be associated with tornado occurrences. The wind blows to the North-East direction at Chuping then changed its direction to East-South at Butterworth station. Sitiawan and Lubok Merbau stations recorded very calm air blowing from North to East direction. There is the probability that the area at that time was pouring with heavy rains which restrain winds from blowing in that region. The interpolated average wind speed map did not justified the evidence of tornado occurrence in Pendang, Kedah. There are two (2) characteristics of the data that need to be improved in future studies. Firstly is the type of statistical calculations. Spatial interpolation relies significantly on the intensities of the values, thus to represent high wind speeds occurrence, the speed of the winds should not be in terms of average, instead it must be in its highest value. Secondly, the characteristics of wind speeds is based on the differences in atmospheric pressure between two points, thus apart from the intensity of the wind speed, distance is also an utmost important factor. As mentioned above, the closes meteorological station from Pendang is Alor Setar which is almost 20 km apart, and the distance between two (2) neighbouring stations of Pendang is Alor Setar and Butterworth, which is approximately 75 km apart. Such distance degrades the accuracy of the wind results especially when dealing with a very small scale wind hazard.

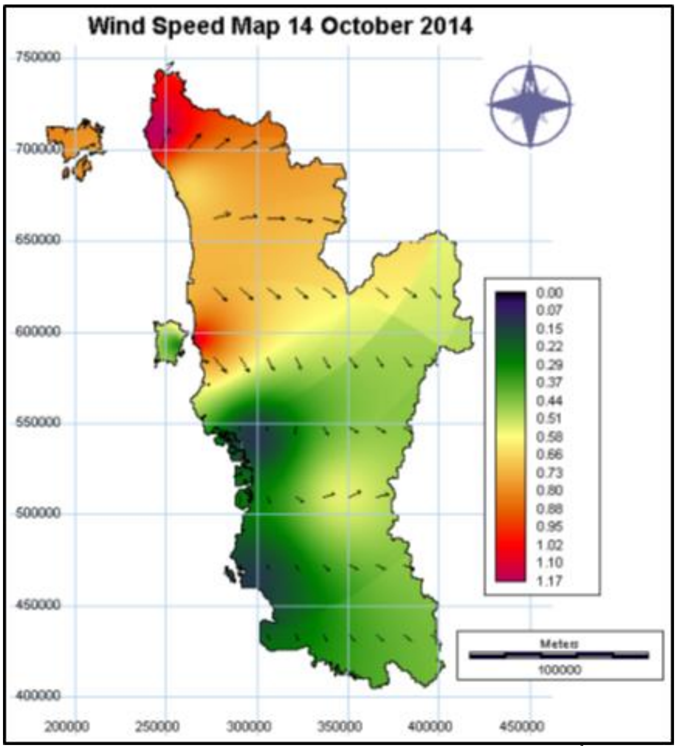


Figure 6.Wind Speed and wind direction Map on the 14th October 2014

Nevertheless, the implementation of this spatial interpolation approach has enabled the relationship between the wind speed and direction to be successfully represented graphically and its significance in terms of describing the characteristic of the wind in general throughout month of October. The wind direction were represented in arrows while the wind speed were represented in terms of gradient of colours where the dark green is the lowest speed and dark red is the highest speed. In addition, the speed of the wind was also represented in terms of the arrows' length, the longer the arrow means the higher the wind speed. Figure 6 shows the highest wind speed between Penang and Perlis states moving outwards north and east, while from Pendang towards a slower wind speed area of Perak state.

5. Conclusion

The application of the spatial interpolation algorithm (IDW) in deriving average wind speed and wind direction maps over a specific period provides an evidence that wind speed and direction differs from one location to another due to many possibilities regarding the environmental surrounding. In conclusion, the wind speed and wind direction are crucial in designing and constructing structures and infrastructures that have sufficient resistance towards the intense wind. Closer distance between the winds data are highly recommended in the wind hazard studies which will create a higher accuracy spatial interpolation maps. This can prevent or reduce wind hazard damages that might occur at any location of the study area.

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