Spatial Patterns of Precipitation, Altitude and Monsoon Directions in Hulu Kelang Area, Malaysia

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ABSTRACT

Malaysia is characterized by a humid tropical climate with heavy rainfall. The annual temperature varies from 26 to 28°C while Malaysia is being one of the wet climate countries with an annual rainfall of approximately 2250 mm/year. Malaysia monsoon is arranged into two rainfall terms: the primary one coincident with the northeast monthly precipitation (December-March) and the other one with the southwest monthly rainfall in conjunction with inter-monsoon periods (April-November). The rainfall events are gauged at points of precipitation measurement networks in Malaysia. But, there is not full mapping of precipitation in relation with elevation all locations especially in mountains. This paper provides the relationship between monthly precipitation and elevation in the Hulu Kelang area based on Geographically Weighted Regression (GWR) method. Three periods of precipitation “the average monthly rainfall and two monsoons” has been studied in this area. The results of regression analyses performed between three conditions of monthly precipitation in the year and altitude. The mean absolute error (MAE) and the root-mean-square error (RMSE) verification results indicated that the whole year rainfall regression model works quite better than other results for interpreting the spatial variability of precipitation. The relation between original normal precipitation (1990-2010) and topography variables showed that study area precipitation is strongly controlled by elevation in the west region. The final map was represented that precipitation in the west region is generally higher than in east region of Hulu Kelang all around the year.

KEYWORDS: Monsoon periods, Geographically Weighted Regression (GWR), mean absolute error (MAE), root-mean-square error (RMSE)

INTRODUCTION

Malaysia is characterized by a humid tropical climate with heavy rainfall (2540 mm p.a. and above), average daily temperatures of 21-32°C and humidity averaging about 85%. Heavy rains
during the monsoon are usually caused by strong convection of air mass in Malaysia. There are two Malaysian monsoon seasons: the primary one is coincident with the northeast monsoon with higher monthly precipitation in (December-March) and the other with the southwest monsoon where monthly rainfall is in conjunction with inter-monsoon periods (April- November). The two monsoon structure angles vary by about 23°. Rainfall is affected by the North-East and South-West monsoons which bring heavy rainfall. It is important that the spatial properties of precipitation in relation with elevation be investigated. The rainfall events are gauged at networked precipitation measurement points in Malaysia. However, full mapping of precipitation in relation to elevation all locations is incomplete, especially in the mountains. The first step to begin any geotechnical project is data collection. The lack of data is problematic in the beginning and interferes with ongoing work. Therefore, it is necessary to use interpolation techniques to extract these records as a continuous surface. In this study, there is no full rainfall event data covering the whole area. And lack of rainfall measurement stations is a reason to use interpolation technique. There are many evaluations such as; precipitation, groundwater pressure, air quality, soil physical properties (Heuvelink, 2006). Such estimates are dependent on related factors such as geology properties, geomorphology map, terrain characterization, and historical data which are used in geographical information system (GIS) in geotechnical projects. The local regression technique is a statistical method that creates relationship between rainfall events and secondary data, such as station elevation and altitude (Salter, 1918; Barry, 1992). Geographically Weighted Regression (GWR) method as the local regression technique was used in this study. GWR overcomes non-stationary regression problems and computes the correlation between spatial variables separately for every point of area. GWR method is part of the statistical model to assess the relationship between precipitation events and variables derived from altitude. However, rain density gauges represent an important pattern in determining an accurate map of the monsoon structures (Berndtsson, 1988; Uvo & Berndtsson, 1995).

GWR method as the relation coefficients between the altitude and the average monthly precipitation were found to be quite significant for rate of rainfall events. The aim of relationship between rainfall and altitude in Hulu Kelang area was to derive a gridded dataset of monthly precipitation from 1990 to 2010. The rainfall mapping index is calculated based on the weight values obtained from the regression method as Weighted Linear Combination (WLC). The relation between monthly average rainfall (1990-2010) and effective variables showed that study area precipitation is strongly controlled by elevation in the west region and by monsoon direction.

GENERAL SITUATION OF THE REGION

Hulu Kelang region in Malaysia is very susceptible to landslides (Mukhlisin et al., 2010). This area is located in Kuala Lumpur, the capital city of Malaysia between 3° 09’ 25” and 3° 13’ 45” East latitude and 101° 44’ 13” and 101° 47’ 51” North longitudes (Fig. 1). Urban development has brought many problems to this region including numerous landslide and mudflow events. The Hulu Kelang area has suffered several fatal landslides caused by rainfall events. There were 28 major landslide events identified as rainfall-induced landslides since 1984. The Highland Towers slide stands as one of the most significant tragedies involving 48 deaths due to tower collapse after several days’ rainfall in 1993.

Based on Malaysian Meteorological Department (MMD), the temperature of the Hulu Kelang area is usually between 29 and 32° C with a mean relative humidity of 65–70%. The average annual temperature is about 25°C. April and June are the highest temperature months, while the relative humidity is lowest in June, July and September.
LAYERS OF THEMATIC DATA

Rainfall-induced landslide is a common geohazard in tropical regions like Malaysia. An understanding of the rate of rainfall in relation with altitude mechanics is thus essential in the investigation of the mechanism of rainfall-induced landslides in the tropical regions. Therefore, this study tried to consider the relationship between rainfall data, digital elevation map (DEM), and slope aspect using geographically weighted regression (GWR) method.

Precipitation

Hulu Kelang climate is generally hot and humid as it is situated in the tropical monsoon region. Precipitation varies between 58 and 420 mm per month in the study area (MMD). There are two
pronounced wet seasons from February to May and from September to December each year. The peak of precipitation is between March and May and also from November to December in the study area. The single-day precipitation high that had been recorded ranged from 87 to 100 mm.

Hulu Kelang normally has more than 200 rainy days per year. Generally, there are 10 to 20 rainy days per month in the wet season, and 10 to 15 days per month in the dry season. The data used in this area is based on daily station data for the period 1990 to 2010 provided by MMD (Malaysian Meteorological department). Monthly precipitation was derived from the daily gauge.

Digital Elevation Map (DEM)

Digital terrain maps are defined as orderly-spaced grids of height amounts that are essential and major for zonal landslide hazard analysis. A DEM is a vector-based triangular irregular network (TIN) structure that represents topography, and has been represented as a raster (a grid of squares, also known as an elevation map when representing height) structure.

Figure 2: Digital elevation map (DEM) of Hulu Kelang area

Digital elevation maps are produced from different original topographic data sources including ground-based surveys, photogrammetrically generated contour maps, and remotely-sensed data. In this study, the digital elevation map was obtained using photogrammetric analysis. A series of aerial
photographs from 1966 to 2003 were provided by the Department of Surveying and Mapping Malaysia (JUPEM). In particular, the aerial photographs from the 2003 flight were sufficient to cover the study areas. The cloud of photographic points extracted from aerial photographs data was therefore considered by GIS tools. In addition to the points identified using the photogrammetric technique, the contour lines of the aerial topographical map at a 1:10000 scale is extracted in standard topographic Ampang and Kampung Kelang Gates Baharu maps published by the director of national mapping, Malaysia 2005. Figure 3.5 represents the range of surface elevation between 50 to 450 m as DEM. The highest elevation is 450 m located on the east side, while the lowest elevation is found on the west side with 50 m.

**Slope Aspect**

Aspect affects hydrologic processes of slopes via evapotranspiration. The hydrologic process, in turn, governs the weathering process, vegetation and root development in soil slopes, particularly in dry environments (Sidle and Ochiai, 2006). The related parameters of aspect include exposure to sunlight, wind direction, precipitation etc. (Cevik and Topal, 2003; Lee, 2005; Galli et al., 2008). Numerous researchers have considered the aspect parameter in landslide susceptibility assessments (Dai et al., 2001; Cevik and Topal, 2003; Suzen and Doyuran, 2004; Komac, 2006, Mohammadi, 2008). Nine different regions were investigated in the present study: flat area (−1°), north (337.5°–22.5°), northeast (22.5°–67.5°), east (67.5°–112.5°), southeast (112.5°–157.5°), south (157.5°–202.5°), southwest (202.5°–247.5°), west (247.5°–292.5°), and northwest (292.5°–337.5°) (Fig. 3).
Rainfall usually increases with altitude. This phenomenon is generally called orographic effect. This effect has been studied in many different studies in many parts of the world (e.g. Alison et al, 2006; Sasi Kumar et al, 2007; Craig, 2009; Haiden and Pistotnik, 2009; Jessica et al, 2010). Increase of precipitation with altitude arises from a number of mechanisms which serve to enhance both the chance of precipitation over hills and the rate of rainfall when it is occurring (Sawyer, 1956; Pedgley, 1970; Barbro and Deliang, 2003). These approaches are well-known, and it is not the purpose of this study to elaborate on them. The rate of rainfall is measured at the points of precipitation measurement networks in Malaysia. However, measurement gauges are not found in all locations especially in the mountains. Therefore need to use a reliable method is required. The relationship between precipitation and altitude as dependent variable can be modelled using conventional ordinary least squares (OLS) and geographically weighted regression (GWR). OLS analysis has been well documented in a number of textbooks for statistics (Propastin and Kappas, 2008). In statistics, the ordinary least squares (OLS) method is used for estimating the unknown parameters in a linear
regression model. This method minimizes the sum of squared vertical distances between the observation data and the prediction results by linear approximation. GWR method as the local regression model dominates in non-stationary regression problems and computes the relevance between spatial variables separately for every point of area. Local parameter estimates can be mapped to view possible lack of a station located at the regression points (Fig. 4).

Figure 4: Inverse Squared Interpolation

These results are the most appropriate and accurate in model prediction. While here there is only a simple description of GWR, a more detailed description can be found by Fotheringham et al. (2002). In low-elevations, most studies have found that a simple linear model seems to fit the observed data well, at least for extended time periods and over relatively small regions. GWR focused on deriving local parameters to be estimated. The model can be written as Eq. (1):

\[ P_{Mon} = C_0 + C_1 (H) + C_2 (A) + \epsilon \text{ (mm)} \] (1)

where \( P \) is the rate of monthly precipitation (mm), \( C_0 \) is the precipitation at sea level (mm) or flat area, \( C_1 \) is the dimensionless rate of increase in rainfall with altitude, or height coefficient (mm/m), \( H \) is the station altitude (m), \( C_2 \) is the change of rainfall with aspect, \( A \) is aspect of that station, and \( \epsilon \) is error term.

In geographically weighted regression (GWR, Brunsdon et al., 1996) “the relationship between rate of rainfall and altitude” is the constant of the coefficients \( C_0, C_1, \text{ and } C_2 \) over space. If we use \((x, y)\) as a coordinate pair, the simple linear model of Eq. (1) can be expanded to Eq. (2).

\[ P = C_0(x, y) + C_1(x, y) (H) + C_2(x, y) (A) + \epsilon \] (2)

RESULTS AND DISCUSSION

The aim of relationship between rainfall and altitude in Hulu Kelang area was to derive a gridded dataset of the average monthly precipitation from 1990 to 2010. To perform this task, two objectives have been dealt with in detail. One considers the influence of topography on the spatial distribution of normal monthly precipitation and the other is concerned with finding the most suitable interpolation method to interpolate monthly precipitation.

To consider the first objective it should be mentioned that the relation between original normal precipitation (1990-2010) and topography variables showed that Malaysian precipitation is strongly controlled by elevation in the Hulu Kelang region, which means that the relation between
precipitation and elevation is quite stable for all months. Both elevation and precipitation increase with altitude.

Second objective is about selective model in this study. From the trend models for the normal precipitation (1990-2010) Geographically Weighted Regression (GWR) method as the local regression technique was employed in Hulu Kelang area. Surveys were conducted in the region, and this model has shown the highest compatibility with this region. A linear precipitation-elevation relationship is calculated based on data over a twenty year period from January-1990 through December-2010 in the study area.

Spatial pattern of precipitation

There are two monsoon periods with two different rainfall intensities and duration in the study area. The direction of rainfall events with the NE monsoon decreased in intensity from the land area, while rainfall coming with the SW monsoon increased in intensity on entering higher regions on the land (Desa and Niemczynowicz, 1996). As a result, three periods of precipitation consisting of average monthly rainfall and two monsoons have been considered valid areas of study in this paper.

First, the results of Geographically Weighted Regression (GWR) method performed between total average of monthly rainfall in the year and altitude was calculated in Eq. (3). The average monthly rainfall equals 164.52 mm (Fig. 5).

\[
P_{\text{Mon}} = 65.536 + 0.4757 \, H + \ldots \text{(mm)}
\]  

Figure 5: Gradient of rainfall-altitude during 20 years (1990-2010)

The equation is completely related to regression of rainfall data of the nearest station to Hulu Kelang area at the same elevation (50- 420m). Figure 5 showed the gradient of rainfall- elevation in the twenty years between 1990 and 2010.

After analysis of the first step, rainfall data are entered into Excel software to analyse two monsoon periods in the study area. Thus, the spatial relation structures of monthly precipitation are
studied in two monsoon periods. The first one coincident with the NE monsoon (December-March) is shown in Figure 6. Regression coefficients during the NE monsoon were calculated based on Eq. (1) with $r^2$ in Northeast monsoon rainfall-altitude about 0.0834 (December to March). The average precipitation during this period equals 122.06 mm.

$$P_{Mon} = 93.234 + 0.3276 H + \ldots \text{ (mm)}$$ \hspace{1cm} (4)

![Figure 6: Gradient of northeast monsoon rainfall-altitude](image)

In Figure 7 is shown the regression analysis of second period of monthly rainfall in the study area with the southwest direction in relationship with elevation (April- November). Calculated regression coefficients during the SW monsoon based on Eq. (1) is computed with $r^2$ in Southwest monsoon rainfall-altitude about 0.4866 (April to November). The average rainfall during this period equals 166.60 mm.

$$P_{Mon} = 16.238 + 0.7462 H + \ldots \text{ (mm)}$$ \hspace{1cm} (5)

![Figure 7: Gradient of southwest monsoon rainfall-altitude](image)
From Figure 5 to Figure 7, one result that can be found is that the trend charts show the increased rate of precipitation in relation to elevation very well, and predicts an increase in the rate of rainfall at other heights. The precipitation in the southwest monsoon is generally higher than in northeast monsoon of Hulu Kelang all year round. The southwestern region of Hulu Kelang receives higher amounts of precipitation than other aspects. The minimum amount of precipitation occurs in June and July, while the maximum occurs in November and April.

**The output maps of the linear regression method based on DEM model**

The main result of this study is that an overlay layer map entitled “Rainfall data, aspect, and DEM” was obtained using ARCGIS tools. Weight assign method is used in this study with correlation between the rate of rainfall events and height of rainfall gauge station. The rainfall mapping index is calculated based on the weight values obtained from the regression method (Eq. (2)).

\[
P = 65.536(x, y) + 0.4757(x, y) \text{Elevation} + 0.01(x, y) \text{Aspect}
\]

The final overlay of effective layers is defined in figure 8. To fulfil this task, the complete correlation between rainfall data, DEM, and southwest and northeast rainfall directions is performed using ARCGIS 10. The relation between monthly average rainfall (1990-2010) and effective variables showed that study area precipitation is strongly controlled by elevation in the west region and monsoon directions. Using different spatial resolutions of the DEM did not result in considerable differences in the correlation, which means that the relation between precipitation and elevation is quite stable from large to small scale. With the increasing of elevation, precipitation also increases.

**Validation of the Geographically Weighted Regression (GWR) method**

The root-mean-square error (RMSE) and the mean absolute error (MAE) are used for validation of modeled precipitation by the nine test stations (See Table 1). RMSE for whole year, NE monsoon, and SW monsoon yielded precipitation values of 7.92 mm, 8.62 mm, and 10.71 mm, respectively, accounting for 15.42%, 7%, and 11.29% of measured precipitation. Upon considering the ordinary least squares (OLS), predicted precipitation values increased only slightly, i.e. by less than 2.9 mm, adjusting for MAE and RMSE. This demonstrates that the residuals are random errors, and that our regression model works quite well for interpreting the spatial variability of precipitation.
This demonstrates that RMSE for the whole year is less than two monsoons, and that a whole year regression model works much better than other results for interpreting the spatial variability of precipitation.

**Table 1:** Validation of the Geographically Weighted Regression (GWR) method

<table>
<thead>
<tr>
<th>Period</th>
<th>After regression only</th>
<th>After ordinary least squares (OLS)</th>
<th>Measured precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAE (mm)</td>
<td>MAE (%)</td>
<td>RSME (mm)</td>
</tr>
<tr>
<td>Whole year</td>
<td>10.15</td>
<td>22.50</td>
<td>7.92</td>
</tr>
<tr>
<td>NE monsoon</td>
<td>23.75</td>
<td>25.86</td>
<td>8.62</td>
</tr>
<tr>
<td>SW monsoon</td>
<td>21.11</td>
<td>26.29</td>
<td>10.71</td>
</tr>
</tbody>
</table>
CONCLUSIONS

This paper provides the relationship between the average monthly precipitation and elevation in the Hulu Kelang area based on Geographically Weighted Regression (GWR) method. The following conclusions can be drawn from three periods of precipitation which are the average monthly rainfall and two monsoon periods in the study area.

1. The GWR represents the relationship between the average monthly precipitation distribution, elevation and two monsoon directions. The final rainfall mapping index calculated is based on the weight values obtained from the regression method which could be written:

\[ P = 65.536(x, y) + 0.4757(x, y) \text{ Elevation} + 0.01(x, y) \text{ Aspect}. \]

2. The root-mean-square error (RMSE) and the mean absolute error (MAE) verification results indicated that the whole year regression model works better than other results for interpreting the spatial variability of precipitation.

3. The relation between original normal precipitation (1990-2010) and topography variables showed that study area precipitation is strongly controlled by elevation in the west region. The final map indicated that precipitation in the west region is generally higher than in east region of Hulu Kelang all year round.

ACKNOWLEDGEMENTS

The authors acknowledge and appreciate the provision of rainfall data by the Ampang Jaya Municipal Council (MPAJ), the Slope Engineering Branch of Public Works Department Malaysia (PWD), and the Department of Irrigation and Drainage Malaysia (DID), without which this study would not have been possible.

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