Rainfall is frequently used as a climate index during prolonged dry seasons and extreme rainfall to determine changes in global climate. This study estimates average total rainfall for the study area based on arithmetic mean and the Thiessen polygon methods. The objective was to analyze rainfall variability based on statistical analysis of variance and to produce maps of rainfall variability using isohyetal contour techniques. Based on the two methods, results showed three distinctive rainfall patterns occurred for consecutive years within the study area.
INTRODUCTION

Water sources such as rainfall are vital for human and animal consumption as well as for agriculture and natural vegetation (Eltahir, 1992). It is important for water resources, and with low rainfall it affects agriculture activity, contributes to climate change, and natural hazards such as floods and droughts (Manfreda et al., 2002). In response to growing concerns about climate change issues, researchers have begun developing methods of assessing rainfall distribution and patterns from rainfall data. This is because rainfall was observed as a frequent indicator of climate change in determining changes in the study of global and local climate change. Rainfall analysis and variability assessment was reported as an indicator of drought analysis in Peninsular Malaysia (Department of Irrigation and Drainage Malaysia, 2005). Furthermore, spatial rainfall analysis is one of the methods available to map rainfall patterns based on annual rainfall data. There many types of techniques involved in estimating annual rainfall such as Isohyetal contour techniques. Isohyetal contour maps produced from this technique are one of the analyses carried out by most of the meteorological office (Shearman and Laster, 1975). Later, the technique was also implemented in another study by Fiedler (2003). Other techniques such as the Thiessen polygon method was used by Chidley and Key (1970), Sing and Birsoy (1975), and Bayrakter et al. (2005). Using annual rainfall data estimation, rainfall patterns can be predicted and monitored.

STUDY AREA

The study is conducted in Negeri Sembilan which is located in western Malaysia. Peninsular Malaysia climate is equatorial with annual averages of temperatures that are between 20.5º and 36º C. The important feature of equatorial climate is the small seasonal variation in incoming solar radiation, both in duration and intensity (Ainuddin, 1998). Negeri Sembilan has two distinctive rainfalls, polar which is moderately dry and moist. Negeri Sembilan received the lowest yearly rainfall for Peninsular Malaysia based on the analysis conducted by Shaharuddin and Noorazuan (2006) for 1987 - 1997. This finding was comparable to Perlis which is located at the Northern part of Peninsular Malaysia. Particularly, this region is facing dry conditions every year during West East Monsoon season. Again, based on research dry conditions were observed in Jelebu and Kuala Pilah. Subsequently, Negeri Sembilan experienced mean monthly relative humidity ranging 80.6% - 85.6% (1997 – 2006). Figure 1 illustrates the location of study area in Malaysia and Negeri Sembilan map. Also the map was presented the location rainfall stations Negeri Sembilan.

MATERIALS AND METHODS

Rainfall Data

Rainfall data was acquired from Malaysian Meteorological Department (Malaysia Meteorological Department, 2008). The location of the stations is shown in previously map in Figure 1. Rainfall data are collected over 24 hour period beginning 08:00 at Malaysia time which equal to 00:00 UTC time. Three rainfall stations are located at the west and east of Negeri Sembilan, respectively. One station is located at the southern part of Negeri Sembilan. In this study, total rainfall stations finalized for the analysis were seven. Stations was named regarding to the location of the station area namely in the valley, estate or plantation for example Ladang Batang Jelai rainfall station which is located at plantation area. Table 1 showed overall rainfall data and stations used for the analysis.

Data Analysis
Data was analyzed based on the two different techniques which are Arithmetic mean and Thiessen Polygon. The techniques were using Spatial Analyst extension in ArcGIS 9.3.1 version software of Geographical Information System (GIS) for analyzing and mapping of the area. For Arithmetic methods, the data analysis was calculated as the amount of rainfall divided by the number of rainfall stations. This technique is simple but it was found least accurate for the area with uniformly distributed and the topography is flat (Grand Solution Manual, 2011). Thiessen Polygon is calculated based on this equation:

Table 1. Complete rainfall data for the stations.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dusun Labu Valley</td>
<td>1527</td>
<td>1883</td>
<td>2204</td>
<td>2616</td>
<td>2379</td>
<td>1892</td>
<td>2628</td>
<td>1935</td>
<td>1719</td>
<td>2262</td>
<td>21044</td>
</tr>
<tr>
<td>Felda Bukit Rokan</td>
<td>1358</td>
<td>1404</td>
<td>1875</td>
<td>2020</td>
<td>1618</td>
<td>1701</td>
<td>1847</td>
<td>1656</td>
<td>1318</td>
<td>1951</td>
<td>16749</td>
</tr>
<tr>
<td>Felda Pasir Besar</td>
<td>2088</td>
<td>1306</td>
<td>1770</td>
<td>1978</td>
<td>1562</td>
<td>2257</td>
<td>2359</td>
<td>1591</td>
<td>1319</td>
<td>1857</td>
<td>18086</td>
</tr>
<tr>
<td>Kirk Estate</td>
<td>1877</td>
<td>1620</td>
<td>1546</td>
<td>3008</td>
<td>2501</td>
<td>2140</td>
<td>2593</td>
<td>1684</td>
<td>1414</td>
<td>1714</td>
<td>20097</td>
</tr>
<tr>
<td>Ladang Batang Jelai</td>
<td>1558</td>
<td>1318</td>
<td>1942</td>
<td>2191</td>
<td>1485</td>
<td>1808</td>
<td>2040</td>
<td>1510</td>
<td>1088</td>
<td>1559</td>
<td>16499</td>
</tr>
<tr>
<td>New Labu Estate</td>
<td>2225</td>
<td>2222</td>
<td>2346</td>
<td>2507</td>
<td>2071</td>
<td>1872</td>
<td>2498</td>
<td>1367</td>
<td>1382</td>
<td>2103</td>
<td>20592</td>
</tr>
<tr>
<td>Regent Estate</td>
<td>1284</td>
<td>1230</td>
<td>1571</td>
<td>1832</td>
<td>1334</td>
<td>1484</td>
<td>1774</td>
<td>1546</td>
<td>1161</td>
<td>1950</td>
<td>15166</td>
</tr>
</tbody>
</table>
Annual Rainfall Estimation
Sheriza, Ainuddin, Hazandy, Helmi Zulhaidi

\[ P_{avg} = \frac{\sum_{i=1}^{n} \left( \frac{A_i}{\sum A_k} \right) P_i}{\sum A_k} \]  

(1)

where \(A_i\) is the area of each polygon and \(P_i\) is the rainfall data at the centre of each polygon, and \(n\) is the total number of polygons. Finally, average rainfall over the basin is \(P_{avg}\). In this study, all the rainfall stations were plotted on the map at an appropriate scale. After that, without crossing any lines straight lines were drawn in order to connect rainfall stations. Next, each connecting line is then bisected and a perpendicular is drawn through the connecting line. Later, the area of each polygon was measured and the total areas for each polygon were computed. Whereas, the isohyetal contour map was produced according to minimum and maximum value of the rainfall data. The process was conducted using Spatial Analyst tools. In this study, yearly contour map was also presented to represent variation of rainfall distribution for different years.

Statistical Analysis

In this study data was statistically analyzed using Analysis of Variance (ANOVA) and Tukey Honestly Significant Difference (HSD) using SPSS software package. The objective is to test significances of the rainfall data among the station and within rainfall years. The significance level was set at \(p=0.05\).

RESULTS AND DISCUSSION

Annual Rainfall

Annual rainfall estimated from Arithmetic technique was 1839 mm. This study found the estimation was closed to a study conducted by Shaharuddin and Noorazuan (2006) with 1846 mm of rainfall. Shaharuddin and Noorazuan (2006) conducted the study from rainfall data of 1983 – 2008 (28 years). Whereas, an annual rainfall was estimated at 2018 mm with the application of Thiessen polygon techniques (as described in Table 2). This indicated an overestimation of average total rainfall from the arithmetic mean method. As the annual rainfall is representing the estimation of average total rainfall, this study was suggested Thiessen polygon as the best technique to estimate the annual rainfall for this study area. This is because the technique is capable to estimate average total rainfall as it manage to take into account of wide area rather than point source area or point location of the stations. Figure 2 illustrates the Thiessen polygon map for this study area.

Statistical Analysis

There were differences in rainfall values within the seven stations (as described in Table 3). Regent Estate showed significant differences with Dusun Labu Valley and New Labu Estate (\(p=0.01\)) and (\(p = 0.035\)). There were no significant differences among other rainfall stations such as Felda Bukit Rokan, Felda Pasir Besar, Kirby Estate and Ladang Batang Jelai. However, there

<table>
<thead>
<tr>
<th>Method</th>
<th>Annual Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic method</td>
<td>1839</td>
</tr>
<tr>
<td>Thiessen Polygon method</td>
<td>2018</td>
</tr>
</tbody>
</table>

Table 2. Annual rainfall for each method.
were differences within years tested ($p = 0.000$) as described in Table 4. In details, rainfall in 1997 was significantly difference with 2000 rainfall with negative relationship ($p = 0.031$). The 1998 were significantly difference with 2000 and 2003 rainfall ($p = 0.003$) and ($p = 0.009$) respectively. For 2000 there was significantly different with 2004 and 2005 rainfall ($p = 0.007$) and ($p = 0.000$). The 2003 rainfall were showed significant difference with 2004 and 2005 ($p = 0.019$) and ($p = 0.000$). This study found there were no significant differences within the 2006 and other years.

**Rainfall Isohyetal Contour Map**

The overall view of yearly rainfall distribution from Isohyetal contour map techniques is shown in Figure 3. The map presented the annual rainfall amount contour for the seven representative stations. Blue color, turquoise, yellow and red indicated rainfall as high, moderate, low and very low, respectively.

**Rainfall distribution from yearly isohyetal contour map**

From the contour map lowest annual rainfall were observed at eastern and southern part of the region. The areas experienced low rainfall value with the contour color was expanded the orange color area towards the section. As shown in Figure 4, 1997 to 2006 map showed red contour area which indicated low rainfall for the consecutive years. However, Regent estate and Felda Bukit Rokan showed the same contour colors which was indicated insignificant differences. The maps were also depicted the extreme distribution of blue color which indicated higher rainfall at western
Table 3. Results of the analysis of variance for rainfall stations.

<table>
<thead>
<tr>
<th>Station</th>
<th>N</th>
<th>Mean</th>
<th>F</th>
<th>sig-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dusun Labu Valley</td>
<td>10</td>
<td>2140.80</td>
<td>3.560</td>
<td>0.004</td>
</tr>
<tr>
<td>Felda Bukit Rokan</td>
<td>9</td>
<td>1644.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Felda Pasir Besar</td>
<td>11</td>
<td>1821.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kirby Estate</td>
<td>10</td>
<td>1977.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladang Batang Jelai</td>
<td>10</td>
<td>1649.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Labu Estate</td>
<td>10</td>
<td>2059.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regent Estate</td>
<td>10</td>
<td>1516.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>70</td>
<td>1827.29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Results of the analysis of variance for years.

<table>
<thead>
<tr>
<th>Year</th>
<th>N</th>
<th>Mean</th>
<th>F</th>
<th>sig-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>7</td>
<td>1702.51</td>
<td>5.708</td>
<td>0.000</td>
</tr>
<tr>
<td>1998</td>
<td>7</td>
<td>1568.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>7</td>
<td>1893.30</td>
<td></td>
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</tr>
<tr>
<td>2000</td>
<td>7</td>
<td>2307.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>7</td>
<td>1849.93</td>
<td></td>
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<tr>
<td>2002</td>
<td>7</td>
<td>1879.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>7</td>
<td>2248.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>7</td>
<td>1612.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>7</td>
<td>1342.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>7</td>
<td>1913.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>70</td>
<td>1831.89</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Isohyetal contour for the study area.
Figure 4. Isohyetal contour map for each year.

part of Negeri Sembilan as mentioned in Shaharuddin and Noorazuan (2006). As summarized, the contour colors distributed into two distinctive areas particularly in 1997 and 2001 maps. Low rainfall observed in 1997 and 1998 could be affected by prolonged dry season which severely affected Southeast Asian countries.
CONCLUSION

This study suggests Thiessen polygon techniques are suitable for estimation of annual rainfall for the study area. Statistical analysis conducted found there were significant differences in rainfall within the stations in Negeri Sembilan. The 2000 rainfall was significantly different from 1997, 1998, 2003, 2004 and 2005. As a conclusion three distinctive rainfall contour patterns occurred within the region. Higher rainfall was attributed to western region of Negeri Sembilan. Whereas, the Regent Estate at the southern part of the region experienced the lowest rainfall for the whole year. This study found higher rainfall occurred near the coastal section due to receive more rain days. Rainfall distribution was clearly distinguished within the region although with shorter period of research conducted. This whole package of techniques can assist environmental and drainage management division for example Department of Irrigation and Drainage Management (DID) and Malaysia Meteorological Department (MET) of Malaysia. The departments are suggesting integrating this technique to implement in their forecasting and monitoring activities toward rainfall pattern particularly during dry season.

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ADDRESS FOR CORRESPONDENCE
M.R. Sheriza
Institute of Tropical Forestry and Forest Products
Universiti Putra Malaysia (UPM)
43400 UPM, Serdang
Selangor, Malaysia
Email: sherizamohdrazali@yahoo.com