ORIGINAL ARTICLE

Patterns of Rainfall in Pattani Province from 1982 to 2001

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Abstract:

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We investigated daily rainfall data collected from 14 meteorological measurement stations in Pattani Province of Southern Thailand with respect to their spatial and seasonal variation. We propose a method, based on five-day aggregation and zero-adjusted log-transformation, that makes such data more amenable to standard statistical analysis, and we use this method to compare the patterns of variation in the data at different locations in the province. We also display methods for graphing the data using a geographical information system, and propose a new plot for simultaneously revealing patterns of variation in both area and season.

Key words : patterns of rainfall, Rainfall in Pattani Province, Pattani Province

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รูปแบบของปริมาณฝนในจังหวัดปัตตานี ในช่วงปี พ.ศ. 2525-2544

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การวิจัยนี้ศึกษาวิธีการนำเสนอรูปแบบการกระจายของปริมาณน้ำฝนตามฤดูกาลและพื้นที่ โดยใช้ข้อมูลปริมาณน้ำฝนรายวัน 14 สถานีของจังหวัดปัตตานีจากกรมอุตุนิยมวิทยา ผู้วิจัยทำการรวมข้อมูลทุก 5 วัน และใช้ลอการิทึมแปลงข้อมูลเพื่อจัดการกับจำนวนวันที่ฝนไม่ตกและให้ข้อมูลเป็นไปตามกฎเกณฑ์ของวิธีการวิเคราะห์ทางสถิติ ใช้วิธีการวิเคราะห์ความแปรปรวนแบบสองทางเปรียบเทียบรูปแบบการกระจายของปริมาณน้ำฝนในพื้นที่ที่ต่างกัน ใช้ระบบสารสนเทศทางภูมิศาสตร์สร้างกราฟแสดงปริมาณน้ำฝน พร้อมทั้งเสนอกราฟชนิดใหม่ที่แสดงรูปแบบการกระจายของปริมาณน้ำฝนตามฤดูกาลและพื้นที่พร้อมกัน

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Pattani Province covers a land area of 2,013.194 square kilometres in Southern Thailand. It lies between latitudes 6º32′ and 6º57′ North, and longitudes 101º01′ and 101º45′ East, bordered to the north by the Gulf of Thailand, to the south-west by Narathiwat Province, to the south and south-west by Yala Province and to the west by Songkhla Province. Pattani is affected by the North-East monsoon from November till February and the South-West monsoon from May till September. The remarkable landscape of Pattani is characterised by its lowland plain area: a large flood plain with scattered small hills in the southern part of its area. A wide range of hills borders Pattani, Yala and Narathiwat Provinces (Ninrat, 1982). This brings Pattani a 7-month period of high rainfall and a 5-month period of drought on average.

Because of the bountiful water supply, most Pattanians are farmers. Normally, an area prevailed upon by the two monsoons is defined a tropical climate zone. However, Pattani still cannot be defined as such because a marked variation of rainfall in Pattani occurs every year, especially from June to September. In some years, there is a paucity of water supply for crops, while in other years, ample quantity of rainfall causes flooding, which brings about a collapse in cultivation and shoreline farming.

According to Hemsuhree (1997) three seasons can be defined on the eastern coast of southern Thailand south of Surattani Province. A dry or low rainfall season occurs between January and April, a moderate rainfall season between May and September, and a high rainfall season between October and December. Uyuenyong *et al*. (1990) investigated the seasonal patterns of rainfall in Pattani. Hemsuhree (1997) compared monthly averages collected from 14 meteorological stations, and concluded that 11 stations had a tropical wet and dry climate while the other three had a tropical monsoon climate.

Statistical analysis and predictive modelling of the distribution of rainfall in Pattani Province is thus useful. We examine the seasonal and spatial distribution of rainfall in the province over the 20-year period from 1982 to 2001. Our aims in this paper are to develop effective statistical analysis methods that can handle the high skewness, irregularity and spatio-temporal correlation that distributions of rainfall data possess (Cressie, 1991), and to investigate methods for effective mapping of such data using a geographical information system. These methods are applied to the Pattani data.

Methodology

Source of data

The data were obtained from recordings of daily precipitation totals (in millimeters) measured from 7 am the previous day until 7 am on the current day, recorded at 14 meteorological stations located in the 12 districts of Pattani Province. Figure 1 shows the locations of these stations and the district boundaries. Each district contains one station, except for Nong Chik and Khok Pho, which contain two stations.

Statistical methods

We grouped the rainfall measurements into 5-day totals, giving 73 periods in a year. This facilitated the statistical analysis by

(a) reducing the correlation between data in successive periods,

(b) reducing the proportion of periods in which there was no rainfall.

However, the comparison over several years was complicated by the fact that February 29 exists only in every fourth year. We adjusted the total from February 25 to March 1 in a leap year by multiplying this total by 5/6.

We used a similar method to handle missing measurements that occurred within any 5-day period. This method involved computing the total for each 5-day period by multiplying the average daily rainfall during the period by 5. Thus, unless all five days in the period were missing, an estimate could be obtained for each period.

The distribution of daily rainfall is highly skewed and thus is not amenable to conventional statistical analysis, which assumes that the data come from normal distributions with constant variance. Aggregating into 5-day periods reduces this skewness, but not enough to justify valid statistical analysis. So we used the data transformation $y = \log(x+1)$, x being a 5-day rainfall total (in mm), prior to fitting statistical models. The unit

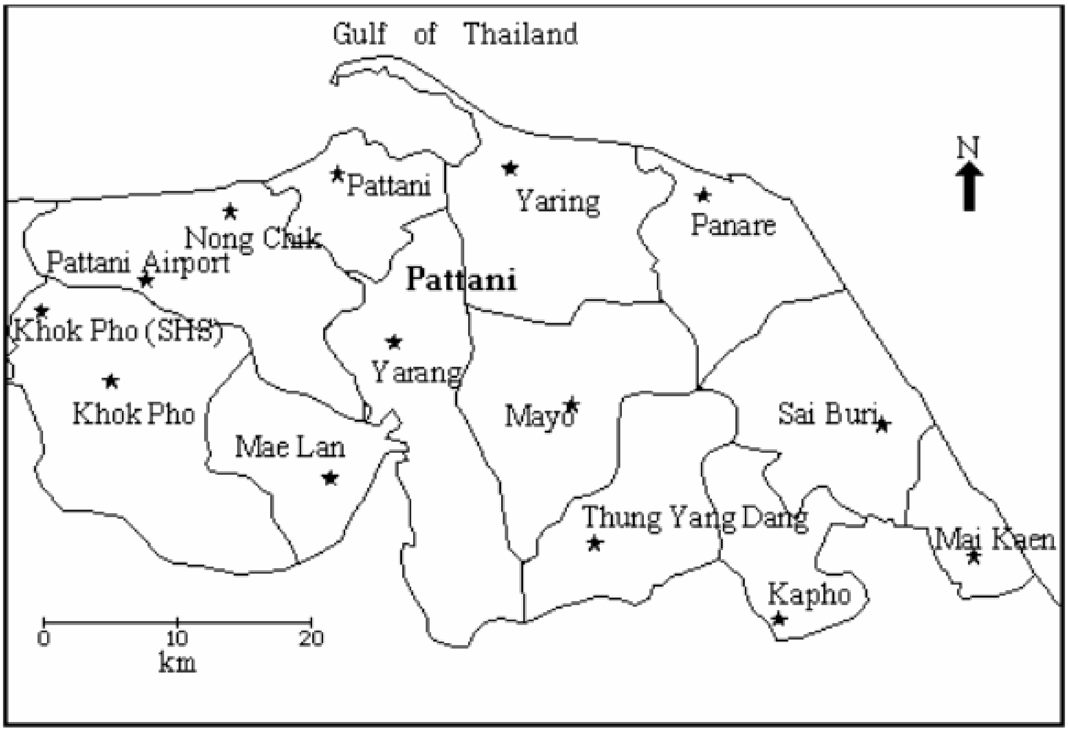

Figure 1. Locations of 14 meteorological stations within the 12 districts in Pattani Province

constant was added to handle periods in which no rain fell. The fitted models were back-transformed using the formula $x = 10^y-1$. This is equivalent to computing averages using zero-adjusted geometric means instead of arithmetic means.

We used two-way analysis of variance to compare the patterns of variation between districts after adjusting for seasonal variations.

Geographical mapping methods

We used thematic maps, range maps, grid maps, and contour maps to display the spatial patterns of the rainfall.

A *thematic map* is a type of map that uses a variety of graphic styles (usually colours or fill patterns) to graphically display information about the mapís underlying data. Thus, a thematic map using data in regions might show one region in dark red (to indicate the region has high values), while showing another region in very pale red (to indicate the region has low values).

A *range map* is a type of thematic map that displays data according to ranges set by the users. The ranges are shaded using colour or patterns.

A *grid map* is a type of thematic map that displays data as continuous colour gradations across the map. This type of thematic map is produced by an interpolation of point data. A grid map may be extended to three dimensions by interpolating point data in three dimensions, where the third dimension is time.

A *contour map* is a way of graphing a variable that takes values in a two-dimensional region. Other methods for graphing such data include 3D wire-frame maps and prism maps (see, for example, the MapInfo 6.5 Users Manual (2002)).

An *ice-cream* plot is a special kind of contour map in which the one of the axes is time and the other is a selected direction through a specified geographical point. It can be obtained as a cross section of a three dimensional grid map, and may be constructed using GIS software as follows. Assume that data are available at (longitude, latitude) coordinates (stations) at successive time periods. A series of range (or contour) maps can thus be constructed for each time period. If these maps are aligned as layers in a vertical stack, they may be regarded as horizontal cross-sectional slices of a three-dimensional tower, which is similar to a tub of Neapolitan ice cream. Now, if we take a vertical cross-section of the tower, the result will be a range (or contour) map in which the vertical axis is time period and the horizontal axis corresponds to the geographical direction of the transect (which could be longitude or latitude or some other direction).

To construct an ice cream plot using standard GIS mapping software, data are needed at points on the transect, which becomes the "longitude" coordinate. The "latitude" coordinate is replaced by the time period and suitably scaled so that the data to be mapped are located on a rectangular grid. When selecting the data from the transects it is advantageous to use data from as many regions as possible, so that the number of transects needed to show the information is minimized. One way of doing this is to first construct the Voronoi polygons surrounding each point. These are defined, for each point (pivotal point) as the polygons containing all those points closer to the pivotal point than to any other point. A desirable transect for creating an ice cream plot is then defined as one that intersects as many Voronoi polygons as possible, thus representing the most data.

Figure 2 shows the Voronoi polygons surrounding the rainfall stations in Pattani Province, and two transects in the ESE direction, one going through Khok Pho station and the other separating the stations at Nong Chik and Pattani Airport. Each transect intersects nine of the 14 regions.

Results

Missing data

Table 1 shows the percentage of periods for which data were missing at each station for each year, where the empty cells denote complete data. Note that rainfall measurements were not recorded in Station 9 (Kapho) before 1983, or before 1984 in Station 10 (Mai Kaen), or before 1989 in Station 12 (Thung Yang Dang), or before 1996 in Station 13 (Mae Lan). Thus, when these years are omitted,

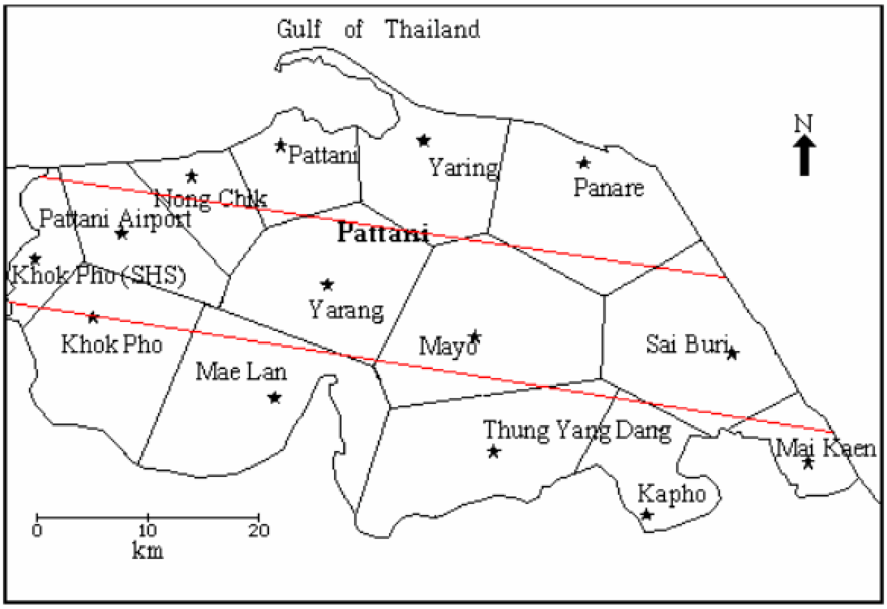

Figure 2. Voronoi polygons and ESE transects used to construct ice cream plots

the percentages of missing data were quite small. For each station, the percentages of 5-day periods for which all data were missing are also shown in Table 1. For six of the stations there were no missing data. For the other eight stations some data were missing, with the percentages of periods having missing data ranging from 0.1% at Yarang to 6.6% at Kapho. The overall proportion of periods for which the data were missing was 1.7%.

Data transformation

Figure 3 (top panel) shows the frequency distribution of the 5-day total rainfall measurements over all 14 stations and 20 years. The distribution is clearly very highly skewed to the right, with coefficient of skewness 4.84. The mean was 25.1 mm and the standard deviation 50.9 mm. The highest recorded 5-day total was 759.1 mm, at Station 10 (Mai Kaen) in period 68 (December 2-6) in 1987, and also at Station 11 (Khok Pho Self-Help Settlement) in the same period. (This coincidence could be due to an error in the data recording process). Of the 18374 5-day periods when measurements were recorded, no rain at all was recorded on 8340 periods (45.4%), and less than 10 mm was recorded on 12331 periods (67.1%).

The bottom panel of Figure 3 shows the frequency distribution of the 5-day total rainfall after taking the transformation log(x+1) of the 5-day totals. The transformation reduced the skewness coefficient to 0.45. The high frequency in the first bin corresponds to measurements between 0 and 0.1 on the transformed data scale, that is, between 0 and $10^{0.1}$-1 = 0.26 mm. There were 8520 5-day periods on which the total rainfall was less than 0.26 mm, corresponding to 46.4% of the periods.

Table 2 shows the averages of the transformed 5-day rainfall totals at each of the 14 stations. This table also includes the averages for the raw (untransformed) totals, as well as the results obtained by reversing the transformation after taking the averages of the transformed data. Since this would be equivalent to taking geometric means if the constant 1 were not added to the data before taking logarithms, these averages are called zero-adjusted geometric means.

Figure 4 shows the 20-year means of the transformed 5-day rainfall totals plotted against

Table 1. Pattern of missing data by station and year.

	Station													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1982							16		100	100		100	100	
1983										100		100	100	
1984										37		100	100	
1985									8			100	100	
1986												100	100	
1987												100	100	
1988												100	100	
1989													100	
1990													100	
1991													100	
1992													100	
1993	58			25								8	100	
1994													100	
1995	49												100	
1996	16													
1997		1							49					
1998														7
1999				84										
2000									58					
2001									16					
Overall	6.2	0	0.1	5.5	0	0	0.8	0	6.6	1.6	0	0.4	0	0.3

Table 2. Averages of transformed rainfall totals in 5-day periods at each station

	Averages (x = raw data) mm		
Station	ave[x]	y = ave[log(1+x)]	10^y-1
Pattani	19.431	0.694	3.945
Sai Buri	30.736	0.963	8.179
Yarang	22.996	0.781	5.041
Khok Pho	19.780	0.605	3.029
Panare	23.957	0.781	5.042
Mayo	29.079	0.871	6.435
Nong Chik	23.620	0.766	4.840
Yaring	22.747	0.703	4.044
Kapho	25.753	0.764	4.801
Mai Kaen	32.947	1.018	9.426
Khok Pho (SHS)	23.778	0.829	5.750
Thung Yang Dang	23.154	0.780	5.028
Mae Lan	35.554	0.983	8.619
Pattani Airport	25.205	0.929	7.484
Overall	25.130	0.730	4.367

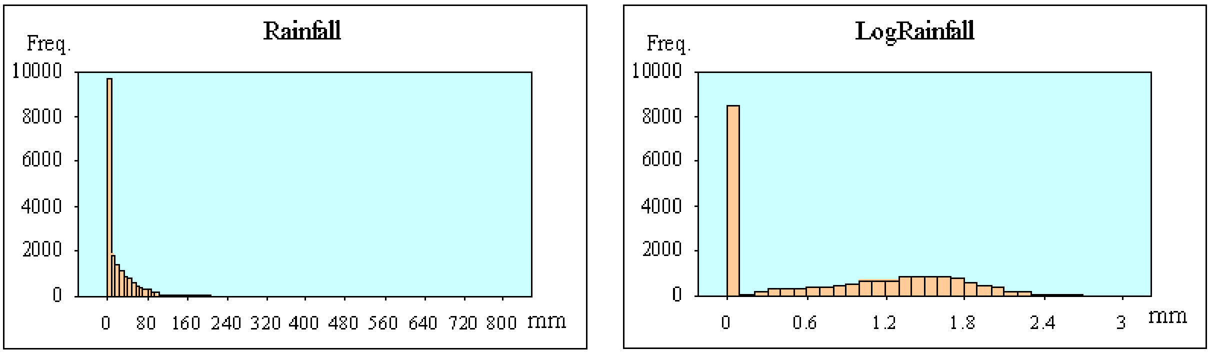

Figure 3. Distribution of rainfall recorded in 5-day periods at 14 stations in Pattani over 1982-2001 (top panel) and after transformation log(x+1) (bottom panel)

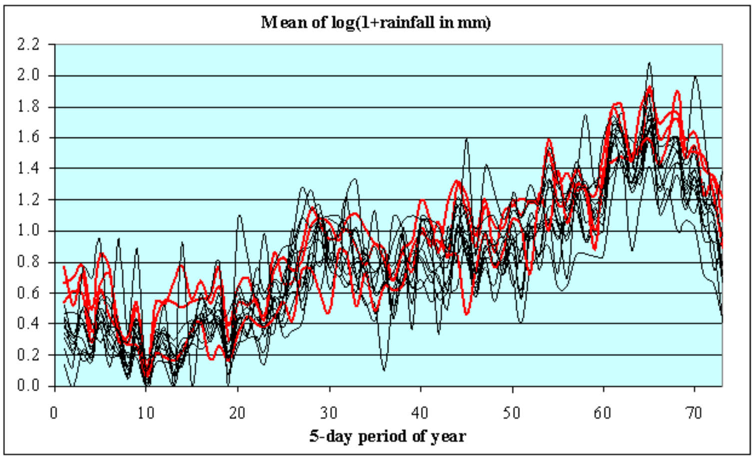

Figure 4. Means of the transformed 5-day rainfall totals for each station

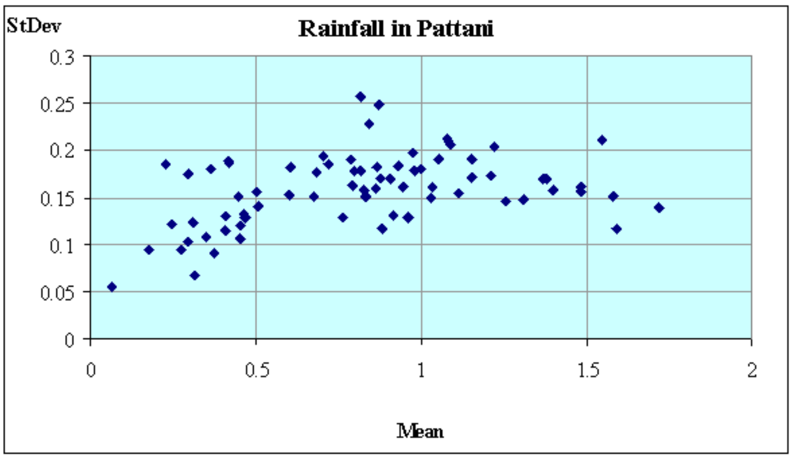

Figure 5. Scatter plot of standard deviations versus means

period for each station. The three stations (Sai Buri, Mai Kaen and Kapho) claimed by Hemsuhree (1997) to have a different climate to the others are plotted with heavy lines.

Analysis of variance

We compared the rainfall at each station using two-way analysis of variance, taking the period as the second factor. We assessed the variance homogeneity assumption by first plotting the standard deviations of the transformed data against their corresponding means, for each of the 73 5-day periods, as shown in Figure 5. The plot shows that the standard deviations were approximately constant, except when values of the mean were small.

Using a normal scores plot of the residuals (not shown) we found that the normality assumption was plausible.

The results show statistically significant differences between the rainfall levels at the different stations ($F_{13,936} = 61.27$, $p < 0.0005$), with the model explaining 93% of the variation. Figure 6 shows means and 95% confidence intervals for the transformed measurements at the 14 stations, where the plotted points corresponding to the means are joined if the Kramer-Tukey test (Cheung and Chan, 1996). Table 3 shows these statistics transformed back to mm.

Table 4 shows the period effects obtained from the one-way analysis of variance, grouped into the three rainfall seasons of the year. These seasons are determined by the averages within the periods. The first season has rainfall less than 3 mm in a typical 5-day period and corresponds to the dry season (periods 1-25, or January 1 - May 5). The second season has rainfall between 3 and 8 mm in a typical 5-day period and corresponds to the moderate rainfall season (periods 26-52, or May 6 - Sept 17), while the third season has typical 5-day rainfall greater than 8 mm and corresponds to the rainy season (periods 53-73, or Sept 18 - Dec 31).

Geographical mapping

Figure 7 shows a range map of the zero-adjusted arithmetic means of the total rainfall in 5-day periods at each station, using the values in Table 2. Just three colour bands are used: below 5 mm (blue), 5-6.5 mm (yellow), and 6.5 mm or more (red).

Figure 8 shows a grid map based on the same data. Because the data are interpolated to create a smooth surface, a greater range of colours is appropriate for this map, and six colour bands selected from the colours of the rainbow are used:

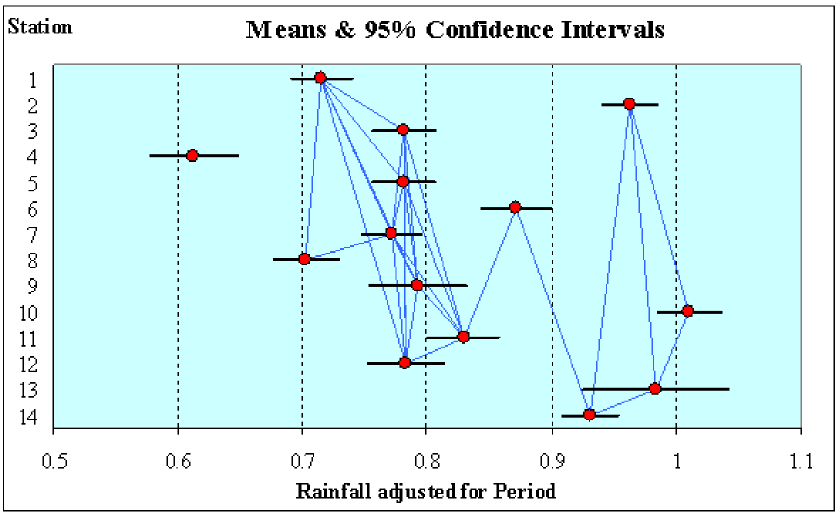

Figure 6. Confidence intervals for means of (transformed) rainfall at the 14 stations

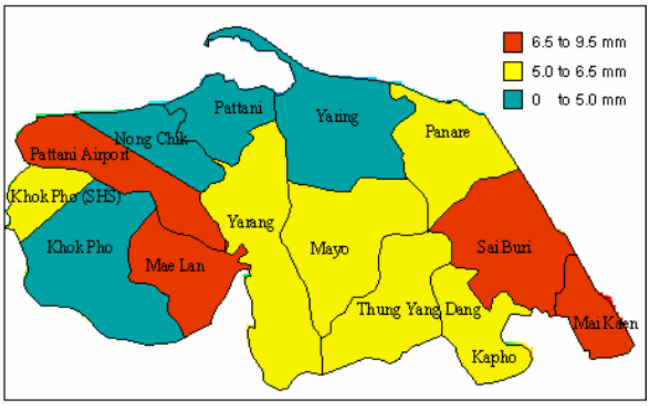

Figure 7. Range map of zero-adjusted geometric mean rainfall in 5-day periods

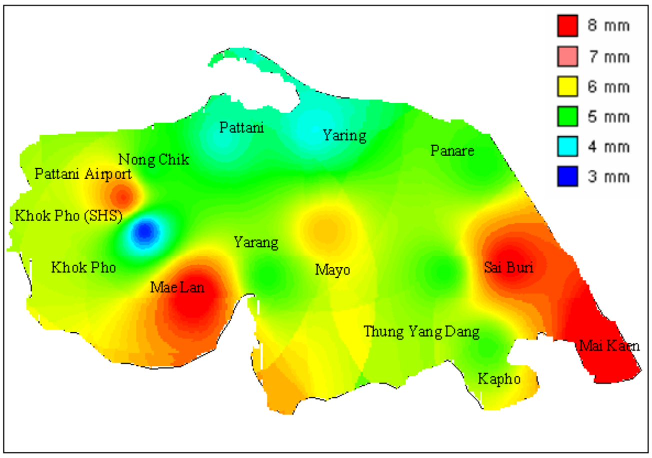

Figure 8. Grid map of zero-adjusted geometric mean rainfall in 5-day periods

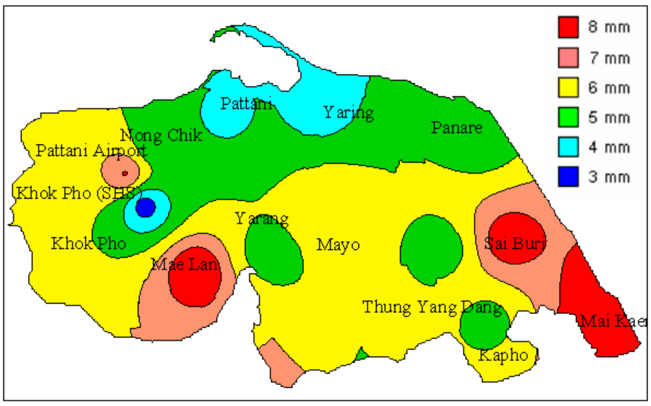

Figure 9. Contour map of zero-adjusted geometric mean rainfall in 5-day periods

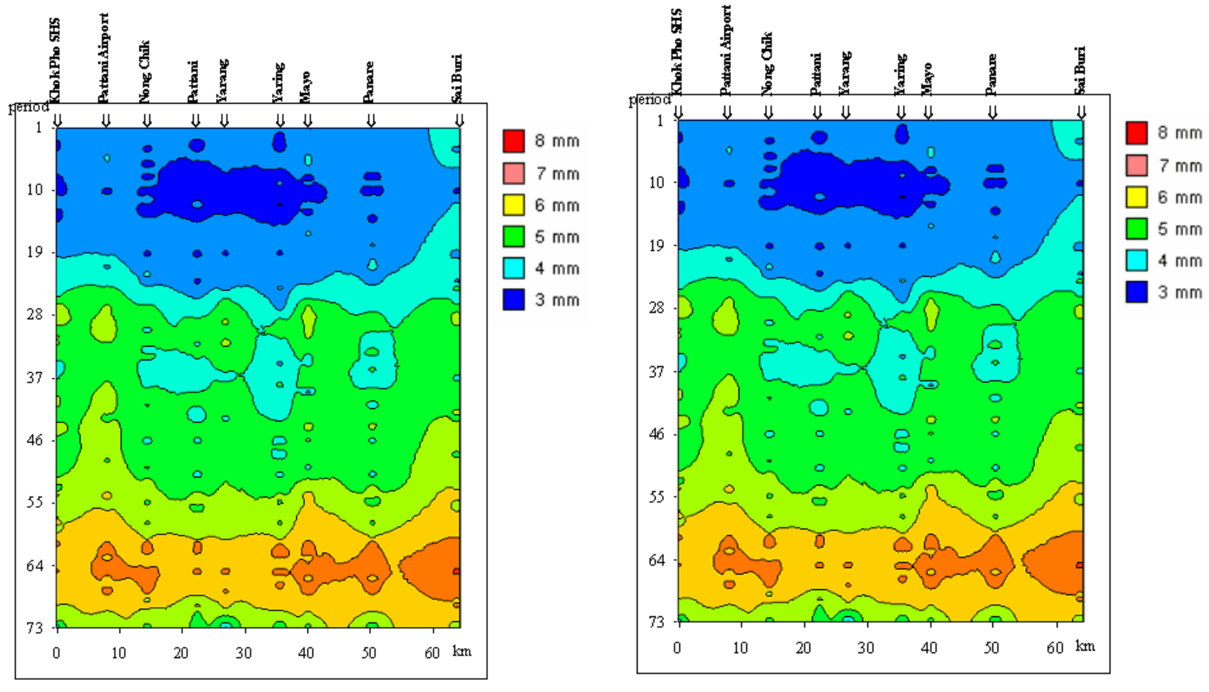

Figure 10. Ice cream plots of zero-adjusted geometric mean rainfall in 5-day periods

below 3.5 mm (violet), 3.5-4.5 mm (blue), 4.5-5.5 mm (green), 5.5-6.5 mm (yellow), 6.5-7.5 mm (orange), and 7.5 mm or more (red).

Using the same colours and scale, the contour map of these data is shown in Figure 9.

Figure 10 shows the ice cream plots. These were created using the two transects shown in Figure 2.

Conclusions

Based on the statistical analysis, which involved aggregating the rainfall in mm (x) into 73 annual 5-day periods and making the transformation log(1+x) to meet statistical assumptions of normality and variance homogeneity, we found differences in the rainfall levels at different locations in Pattani Province. It was lower at Khok Pho (zero-adjusted geometric mean 3.03 mm in a five-day period) and higher at Mai Kaen (9.43 mm), Mae Lan (8.62 mm), Sai Buri (8.18 mm) and Pattani Airport (7.48 mm). The seasonal pattern of the rainfall distribution appeared to be similar at each station, with the highest quantity recorded in periods 53-73 (September 18 - December 31), a moderate quantity recorded in periods 26-52 (May 6 - September 17), and the lowest quantity recorded in periods 1-25 (January 1 - May 5). This result confirms some of the findings in a previous study by Hemsuhree (1997).

We also investigated methods for displaying spatio-temporal maps of the rainfall patterns based on cross-sections of three-dimensional contour maps ("ice-cream" plots). The plot reveals how the quantity of rainfall increases during the year and across the province in the ESE direction, with similar patterns for two transects at a distance 15 km apart.

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Table 3. Zero-adjusted arithmetic means and 95% confidence intervals

Station	Mean	95% CI	
Pattani	4.190	3.906	4.490
Sai Buri	8.180	7.736	8.646
Yarang	5.043	4.702	5.404
Khok Pho	3.101	2.777	3.453
Panare	5.042	4.713	5.391
Mayo	6.436	5.979	6.922
Nong Chik	4.908	4.603	5.231
Yaring	4.045	3.759	4.347
Kapho	5.194	4.665	5.772
Mai Kaen	9.236	8.648	9.859
Khok Pho SHS	5.750	5.328	6.201
Thung Yang Dang	5.060	4.655	5.494
Mae Lan	8.619	7.416	9.994
Pattani Airport	7.528	7.112	7.965

Table 4. Rainfall totals in 5-day periods estimated from one-way analysis of variance model

Period	y	10^y-1
1	0.406	1.55
2	0.322	1.10
3	0.388	1.44
4	0.255	0.80
5	0.485	2.05
6	0.370	1.34
7	0.283	0.92
8	0.165	0.46
9	0.327	1.12
10	0.043	0.10
11	0.255	0.80
12	0.302	1.00
13	0.213	0.63
14	0.285	0.93
15	0.315	1.07
16	0.385	1.43
17	0.377	1.38
18	0.421	1.64
19	0.204	0.60
20	0.429	1.69
21	0.428	1.68
22	0.445	1.78
23	0.365	1.32
24	0.524	2.34
25	0.540	2.47
overall	0.341	1.27

Period	y	10^y-1
26	0.640	3.37
27	0.743	4.53
28	0.844	5.99
29	0.880	6.59
30	0.771	4.90
31	0.822	5.63
32	0.809	5.44
33	0.722	4.27
34	0.694	3.94
35	0.613	3.10
36	0.626	3.22
37	0.629	3.25
38	0.749	4.61
39	0.686	3.86
40	0.819	5.60
41	0.786	5.12
42	0.732	4.40
43	0.725	4.30
44	0.944	7.79
45	0.871	6.44
46	0.704	4.06
47	0.885	6.67
48	0.772	4.91
49	0.779	5.02
50	0.874	6.49
51	0.752	4.66
52	0.933	7.57
overall	0.771	5.03

Period	y	10^y-1
53	0.945	7.81
54	1.108	11.82
55	0.957	8.05
56	0.989	8.74
57	1.137	12.71
58	1.016	9.38
59	0.994	8.87
60	1.091	11.33
61	1.434	26.16
62	1.419	25.25
63	1.213	15.33
64	1.296	18.78
65	1.503	30.85
66	1.246	16.61
67	1.347	21.22
68	1.354	21.62
69	1.139	12.76
70	1.262	17.29
71	0.991	8.79
72	0.992	8.82
73	0.760	4.76
overall	1.152	14.62

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