Research Journal of Applied Sciences, Engineering and Technology 11(8): 841-846, 2015
DOI: 10.19026/rjaset.11.2093
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: May 11, 2015 Accepted: June 22, 2015 Published: November 15, 2015

Research Article

Neyman Scott Rectangular Pulse Modeling for Storm Rainfall Analysis in Peninsular Malaysia

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Abstract: The objective of this study is to evaluate the application Neyman-Scott Rectangular Pulse (NSRP) modeling in describing the storm rainfall in Peninsular Malaysia. Hourly rainfall data for the periods of 1970 to 2008 from 50 rain-gauge stations in Peninsular Malaysia is used in this study. The rain-gauge stations are divided into four sub regions, namely northwest, west, southwest and east. The goodness of fit of the NSRP model to the observation is tested first before further application of the model. The results showed the NSRP model is able to represent the rainfall data in Peninsular Malaysia.

Keywords: Malaysia, NSRP, storm rainfall

INTRODUCTION

The issues of climatic change and global warming receive considerable attention from various researchers nowadays, particularly with regard to the effect of the behavior of the storm rainfall to the community. In relation to that, the analysis of storm rainfall is becoming important in many areas, particularly in water-related sectors such as agriculture, hydrology and water resource management. With the expansion of irrigated agriculture, coupled with the development of industrialization and the rapid growth of population, such analysis can be utilized in rainfall forecasting and eventually, decision making. Studies in storm rainfall such as the intensity of rainfall, extreme rainfall, total rainfall and heavy rains have attracted much attention from scientists throughout the world, such as researches carried out by Lana *et al*. (2004), Martinez *et al*. (2007), Aravena and Luckman (2009), Sen Roy (2009), Turkes *et al*. (2008) and Burgueño *et al*. (2004, 2005, 2010).

There have been a few published works on the behavior of storm rainfall in Peninsular Malaysia. Among them are works on detecting trends in dry and wet spells over the Peninsula during monsoon seasons (Deni *et al*., 2008, 2010a, 2010b), changes in extreme rainfall events (Zin *et al*., 2010), changes in daily rainfall during monsoon seasons (Suhaila *et al*., 2010) and analysis of rainfall variability (Wong *et al*., 2009). In these studies, various objectives and approaches have been highlighted in describing the characteristics of rainfall in this area.

DATA AND METHODOLOGY

Peninsular Malaysia is situated in the tropics at between 1 and 7 north of the equator. In general, the country experiences a wet and humid tropical climate throughout the year, characterized by high annual rainfall, humidity and temperature. Peninsular Malaysia has a uniform temperature of 25.5-32°C throughout the year. Normally, annual rainfall is between 2,000 and 4,000 mm, while the annual number of wet days ranges from 150 to 200. The climate of Peninsular Malaysia is described two monsoons separated by two inter-monsoons. The Southwest Monsoon (SWM) occurs from May to September and the Northeast Monsoon (NEM) occurs from November to March. The two inter-monsoons occur in April (FIM) and October (SIM). In Peninsular Malaysia, the Main Range Mountains, known locally as Banjaran Titiwangsa, run southward from the Malaysia-Thai border in the north, spanning a distance of 483 km and separating the eastern and western parts of the Peninsula. During the NEM season, exposed areas in the eastern part of the Peninsula receive heavy rainfall. In contrast, areas

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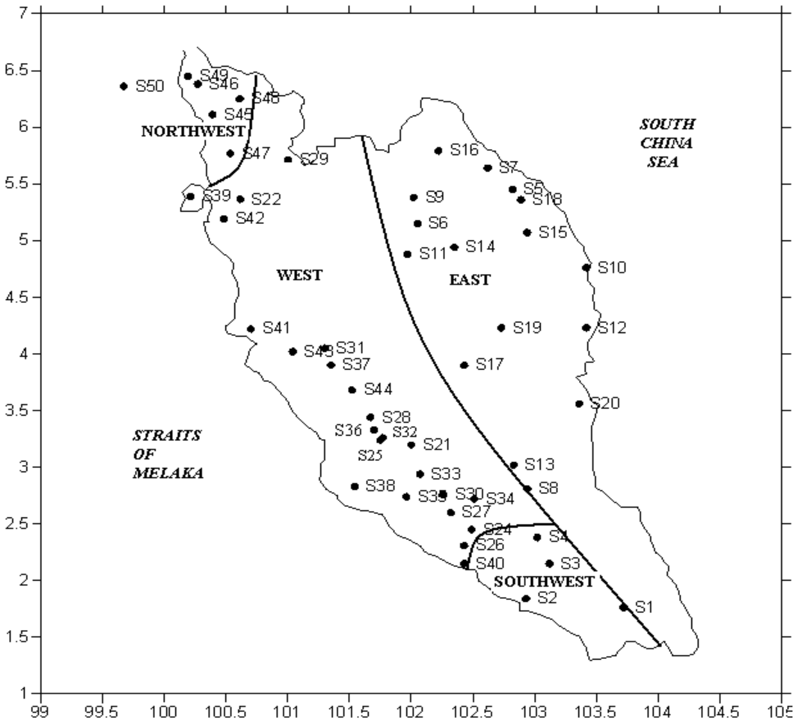

Fig. 1: Geographical regions and the selected 48 stations in Peninsular Malaysia

sheltered by the Main Range (Fig. 1), are more or less free from its influence.

In this study, hourly rainfall data from 48 rain gauge stations were used. The data was obtained from the Malaysian Meteorological and Drainage and Irrigation Departments for the period of 1970-2008. The 48 stations are then divided into four categories in this study. The segregation of the stations into categories are based on studies done by Dale (1959) and Deni *et al*. (2008). Dale (1959) has delineated five rainfall regions in Peninsular Malaysia to northwest, west, Port Dickson-Muar coast, southwest and east. In this study, however, the stations located on the Port Dickson-Muar coast were combined with those in the southwest region. The list of the 48 stations with their respective regions is provided in Table 1 and geographical regions and the selected 48 stations can be depicted as in the Fig. 1.

The Neyman-Scott Rectangular Pulse (NSRP) modeling is used to model the rainfall amount at each station Peninsular Malaysia. The single-site NSRP model is characterized by a flexible structure in which the model parameters broadly relate to the underlying physical features observed in rainfall events. In theory, the NSRP model assumes that the storm origins follow a Poissonian process with parameter λ. Then, a random number of cell $E(C)$ origins are displaced from the storm origins by exponentially distributed distances with parameter β. A rectangular pulse, with duration and intensity expressed by other two independent random variables, assumed to be exponentially distributed with parameters η and $E(X)$ respectively, is associated at each cell origin. The total intensity at any point in time is given by the sum of all the active cell intensities at that particular point. The NSRP model therefore has a total of five parameters that can be estimated by minimizing an objective function, evaluated as sum of normalized residuals between the statistical properties of the observed and their theoretical expressions (Rodriguez-Iturbe *et al*., 1987a, 1987b; Cowpertwait, 1991; Cowpertwait *et al*., 1996). This model is able to produce statistics estimation values close to the observed values (Cowpertwait *et al*., 1996).

The main feature of the NSRP model can be summarized as follows:

- Every storm arrival, represented by l_i, $i = 1, 2, 3,\ldots$ is exponentially distributed in poisson process with parameter λ.
- Every rain cells, c_{ij}, i = storm index of i, j = rain cell index of storm-i, has poisson or geometry distribution with mean of $E(C)$.
- Every waiting time for cells after the storm origin, b_{ik}, i = index storm of i, k = time of rain cell at storm-i, will be exponentially distributed with mean β.
- In every rain cell, there are two other parameters forming cluster as rain cell intensity x_{jh}, j = jth cell, h = intensity at j th cell, which is exponentially distributed with mean $E(X)$ and the duration of rain t_{js}, j = jth cell, s = duration at jth cell, is exponentially distributed with mean η.

Table 1: The list of 48 rain gauges stations with their respective regions and geographical coordinates

Region	Stations	Code	State	Longitude	Latitude
Southwest	Kota Tinggi	S1	Johor	103.72	1.76
	Batu Pahat	S2	Johor	102.93	1.84
	Endau	S3	Johor	103.62	2.65
	Labis	S4	Johor	103.02	2.38
East	Batu Hampar	S5	Trengganu	102.82	5.45
	Bertam	S6	Kelantan	102.05	5.15
	Besut	S7	Trengganu	102.62	5.64
	Sg Chanis	S8	Pahang	102.94	2.81
	Dabong	S9	Kelantan	102.02	5.38
	Dungun	S10	Trengganu	103.42	4.76
	Gua Musang	S11	Kelantan	101.97	4.88
	Kemaman	S12	Trengganu	103.42	4.23
	Sg Kepasing	S13	Pahang	102.83	3.02
	Kg Aring	S14	Kelantan	102.35	4.94
	Kg Dura	S15	Trengganu	102.94	5.07
	Machang	S16	Kelantan	102.22	5.79
	Paya Kangsar	S17	Pahang	102.43	3.90
	Kg Sg Tong	S18	Trengganu	102.89	5.36
	Ulu Tekai	S19	Pahang	102.73	4.23
	Pekan	S20	Pahang	103.36	3.56
West	Ampang	S21	Selangor	102.00	3.20
	Bkt Bendera	S22	Pulau Pinang	100.27	5.42
	Chin Chin	S24	Melaka	102.49	2.29
	Genting Klang	S25	W. Persekutuan	101.75	3.24
	Jasin	S26	Melaka	102.43	2.31
	Kalong Tengah	S28	Selangor	101.67	3.44
	Kampar	S29	Perak	101.00	5.71
	Kg Sawah Lebar	S30	N. Sembilan	102.26	2.76
	ladang bikam	S31	Perak	101.30	4.05
	Kg Kuala Sleh	S32	W. Persekutuan	101.77	3.26
	Petaling	S33	N. Sembilan	102.07	2.94
	Rompin	S34	N. Sembilan	102.51	2.72
	Seremban	S35	N. Sembilan	101.96	2.74
	Sg Batu	S36	W. Persekutuan	101.70	3.33
	Sg Bernam	S37	Selangor	101.35	3.70
	Sg Mangg	S38	Selangor	101.54	2.83
	Sg Pinang	S39	Pulau Pinang	100.21	5.39
	Merlimau	S40	Melaka	102.43	2.15
	Siti Awan	S41	Perak	100.70	4.22
	Sg Sp Ampat	S42	Pulau Pinang	100.48	5.29
	Telok Intan	S43	Perak	101.04	4.02
	Tanjung Malim	S44	Perak	101.52	3.68
Northwest	Alor Setar	S45	Kedah	100.39	6.11
	Arau	S46	Perlis	100.27	6.43
	Baling	S47	Kedah	100.74	5.58
	Kuala Nerang	S48	Kedah	100.61	6.25
	Padang Katong	S49	Perlis	100.19	6.45
	Pdg Mat Sirat	S50	Kedah	99.67	6.36

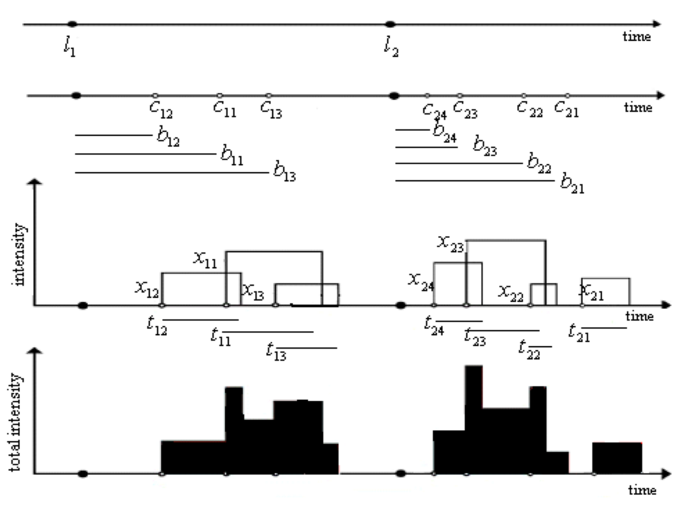

Fig. 2: NSRP modelling l_i storm arrival time, c_{ij} of rain cell, b_{ik} waiting time of rain cell, t_{js} duration of rain cell and x_{jh} intensity of rain cell

These four conditions can be depicted as in the Fig. 2.

Hourly data from each station is fitted with NSRP and the resulting NSRP parameters ($\lambda, E(X), E(C), \beta$ and η) are recorded on monthly basis. To check on how well the NSRP model obtained is able to represent the actual rainfall data, the mean of the 1-hour rainfall and the probabilities of the 1 and 24-hour rainfall estimated from the model are compared with these statistics values calculated from the observed data.

RESULTS

Table 2 shows contain the estimated parameters of the NSRP model for the 48 stations in the November and December. Rainfall data is generated based on the NSRP model with parameters identified for each station and several statistics values, in particular, the mean and probability values of the 1 and 24-hour rainfall amount are then calculated. These statistics are chosen for their ability to describe the condition of a data set.

To check on how well the NSRP model obtained able to represent the actual rainfall data, the mean of the

Table 2: List NSRP parameter for the 48 rain gauges stations

		November					December				
Region	Station	λ	E (X)	E (C)	β	η	λ	E (X)	E (C)	β	η
Southwest	S1	0.025	93.70	2.560	0.116	2.23	0.012	56.82	7.880	0.078	1.48
	S2	0.028	221.46	1.460	0.020	2.08	0.021	70.67	4.580	0.109	2.56
	S3	0.033	15.580	1.390	0.221	2.22	0.012	5.960	5.700	0.081	2.16
	S4	0.003	74.40	16.28	0.001	1.48	0.015	85.30	5.410	0.112	1.96
East	S5	0.012	12.69	4.340	0.068	3.03	0.021	11.94	3.220	0.197	3.08
	S6	0.022	5.280	5.770	0.098	2.23	0.012	4.310	15.23	0.081	2.13
	S7	0.012	8.650	13.68	0.034	1.50	0.009	4.930	22.14	0.026	1.03
	S8	0.027	89.30	2.800	0.193	2.31	0.012	94.99	10.56	0.097	2.22
	S9	0.017	6.240	7.690	0.062	1.64	0.011	5.390	16.08	0.061	1.60
	S10	0.014	5.170	11.08	0.054	1.08	0.010	3.860	14.21	0.045	0.71
	S11	0.026	7.870	3.810	0.088	2.12	0.010	4.750	10.91	0.055	1.56
	S12	0.013	56.95	14.20	0.071	1.42	0.010	35.41	36.41	0.060	1.32
	S13	0.029	95.27	2.670	0.132	2.31	0.012	69.41	7.450	0.054	1.67
	S14	0.022	7.240	5.490	0.050	1.92	0.012	6.230	17.26	0.066	1.83
	S15	0.021	8.160	8.950	0.047	1.91	0.013	4.990	20.43	0.040	1.24
	S16	0.015	4.710	14.23	0.095	1.72	0.008	3.650	94.52	0.097	3.23
	S17	0.020	7.410	3.750	0.066	1.98	0.014	5.270	6.690	0.053	1.68
	S18	0.020	8.060	9.270	0.054	1.77	0.013	7.870	13.76	0.034	1.01
	S19	0.023	13.26	5.630	0.126	3.31	0.012	6.260	44.97	0.111	4.95
	S20	0.025	8.360	3.540	0.083	1.54	0.011	6.090	10.71	0.055	0.96
West	S21	0.007	5.670	10.95	0.037	2.30	0.008	7.620	5.650	0.096	2.82
	S22	0.027	8.640	2.830	0.074	1.74	0.012	8.830	2.900	0.067	1.97
	S24	0.028	2.710	11.38	0.478	3.02	0.012	5.960	5.700	0.081	2.16
	S25	0.037	82.69	2.570	0.121	2.08	0.009	85.79	6.550	0.042	2.03
	S26	0.031	6.280	7.300	0.786	4.92	0.009	5.150	10.32	0.076	2.62
	S28	0.051	6.690	2.440	0.177	1.95	0.016	5.900	5.050	0.059	1.86
	S29	0.038	10.65	2.510	0.089	2.13	0.026	11.14	2.480	0.076	1.94
	S30	0.015	79.97	4.670	0.044	2.15	0.014	44.10	5.340	0.066	1.80
	S31	0.032	8.780	3.260	0.085	2.18	0.038	11.580	2.800	0.798	3.23
	S32	0.048	110.72	1.950	0.263	2.52	0.015	107.19	3.470	0.051	2.63
	S33	0.026	61.91	3.220	0.139	2.16	0.016	60.17	4.110	0.080	2.02
	S34	0.023	60.32	4.920	0.080	2.17	0.014	44.12	6.910	0.061	1.69
	S35	0.034	7.090	3.150	0.169	2.14	0.014	6.560	4.530	0.069	2.07
	S36	0.038	129.97	2.350	0.051	2.48	0.033	97.96	2.420	0.170	2.46
	S37	0.036	8.510	3.460	0.186	2.74	0.020	11.08	3.780	0.091	2.83
	S38	0.037	63.64	4.470	0.658	3.49	0.024	97.53	3.780	0.198	3.71
	S39	0.030	7.270	3.570	0.281	2.07	0.010	6.870	3.980	0.103	1.82
	S40	0.024	8.450	4.980	0.141	4.31	0.011	4.970	6.610	0.102	2.36
	S41	0.031	6.560	2.550	0.236	2.05	0.017	8.570	3.860	0.092	2.31
	S42	0.028	6.780	3.200	0.100	1.65	0.016	6.770	3.190	0.122	1.79
	S43	0.033	7.640	3.380	0.186	2.19	0.024	8.670	3.100	0.181	2.01
	S44	0.037	7.940	3.310	0.110	2.22	0.022	8.860	3.120	0.086	2.43
Northwest	S45	0.007	2.090	16.27	0.113	2.05	0.007	5.460	7.400	0.086	2.58
	S46	0.010	5.700	16.49	0.054	2.61	0.005	8.230	24.89	0.067	3.98
	S47	0.012	5.040	5.970	0.127	2.39	0.006	9.600	5.570	0.097	3.34
	S48	0.022	4.110	5.160	0.147	1.89	0.008	3.620	6.920	0.080	1.51
	S49	0.078	67.53	1.010	0.179	2.57	0.003	16.50	22.20	0.048	1.09
	S50	0.011	6.890	8.100	0.061	2.43	0.008	7.680	4.090	0.098	2.86

Table 3: Comparison between the statistics estimated from the NSRP model with the statistics obtained from the observed data for the 48 rain gauges stations

		November						December					
Region	Station	MO	ME	KO	KE	KO2	KE2	MO	ME	KO	KE	KO2	KE2
Southwest	S1	2.74	2.72	0.08	0.08	0.57	0.57	3.31	3.54	0.11	0.12	0.51	0.47
	S2	3.45	4.38	0.11	0.06	0.64	0.61	2.73	2.67	0.11	0.11	0.56	0.58
	S3	0.29	0.32	0.10	0.06	0.58	0.58	0.19	0.19	0.08	0.08	0.44	0.45
	S4	2.61	2.58	0.09	0.08	0.55	0.69	2.80	3.52	0.11	0.10	0.49	0.47
East	S5	0.23	0.22	0.06	0.06	0.42	0.44	0.27	0.26	0.08	0.07	0.47	0.49
	S6	0.29	0.30	0.14	0.14	0.66	0.63	0.32	0.36	0.16	0.17	0.60	0.52
	S7	0.89	0.93	0.20	0.20	0.70	0.69	0.96	0.98	0.27	0.27	0.72	0.72
	S8	2.91	2.96	0.09	0.09	0.58	0.57	4.23	5.62	0.13	0.13	0.58	0.48
	S9	0.47	0.50	0.16	0.16	0.69	0.64	0.54	0.61	0.18	0.19	0.66	0.57
	S10	0.70	0.76	0.21	0.21	0.73	0.65	0.71	0.76	0.21	0.22	0.64	0.58
	S11	0.36	0.37	0.12	0.12	0.68	0.66	0.32	0.34	0.14	0.14	0.56	0.52
	S12	6.68	7.66	0.20	0.20	0.70	0.59	8.31	9.42	0.26	0.27	0.68	0.58
	S13	3.18	3.25	0.10	0.10	0.65	0.62	3.43	3.60	0.11	0.11	0.56	0.53
	S14	0.45	0.45	0.15	0.15	0.73	0.73	0.58	0.69	0.19	0.20	0.69	0.57
	S15	0.78	0.80	0.22	0.22	0.79	0.78	1.00	1.04	0.29	0.29	0.73	0.73
	S16	0.53	0.58	0.19	0.20	0.65	0.57	0.74	0.88	0.22	0.23	0.57	0.46
	S17	0.28	0.28	0.10	0.10	0.60	0.60	0.30	0.29	0.12	0.12	0.57	0.58
	S18	0.80	0.83	0.21	0.21	0.75	0.74	0.97	1.45	0.25	0.26	0.75	0.74
	S19	0.40	0.52	0.14	0.13	0.71	0.61	0.48	0.69	0.20	0.23	0.64	0.53
	S20	0.47	0.48	0.12	0.12	0.64	0.64	0.70	0.76	0.17	0.17	0.61	0.55
West	S21	0.18	0.18	0.09	0.09	0.46	0.45	0.12	0.13	0.05	0.05	0.33	0.32
	S22	0.38	0.38	0.11	0.11	0.65	0.66	0.16	0.16	0.05	0.05	0.39	0.39
	S24	0.29	0.29	0.10	0.15	0.58	0.57	0.19	0.19	0.08	0.08	0.44	0.45
	S25	3.80	3.74	0.12	0.12	0.68	0.71	2.37	2.45	0.08	0.08	0.48	0.46
	S26	0.28	0.29	0.12	0.11	0.56	0.57	0.17	0.18	0.09	0.09	0.41	0.40
	S28	0.43	0.43	0.16	0.15	0.75	0.79	0.27	0.26	0.11	0.11	0.55	0.58
	S29	0.49	0.48	0.13	0.12	0.70	0.74	0.37	0.37	0.09	0.09	0.60	0.61
	S30	2.70	2.63	0.09	0.09	0.56	0.58	1.81	1.79	0.10	0.10	0.51	0.51
	S31	0.44	0.43	0.13	0.13	0.68	0.73	0.36	0.38	0.12	0.09	0.63	0.63
	S32	4.14	4.13	0.11	0.11	0.73	0.73	2.16	2.13	0.07	0.07	0.51	0.52
	S33	2.42	2.40	0.10	0.10	0.59	0.59	1.97	1.94	0.08	0.08	0.49	0.50
	S34	3.21	3.17	0.14	0.14	0.65	0.66	2.43	2.45	0.12	0.12	0.56	0.55
	S35	0.36	0.35	0.13	0.13	0.64	0.67	0.21	0.21	0.08	0.08	0.48	0.50
	S36	4.67	4.64	0.11	0.11	0.77	0.78	3.15	3.15	0.10	0.10	0.63	0.63
	S37	0.40	0.39	0.14	0.13	0.67	0.69	0.30	0.29	0.09	0.09	0.54	0.56
	S38	2.99	2.98	0.11	0.11	0.63	0.63	2.47	2.42	0.09	0.09	0.53	0.55
	S39	0.37	0.37	0.11	0.11	0.60	0.59	0.15	0.16	0.05	0.05	0.35	0.34
	S40	0.24	0.23	0.12	0.11	0.56	0.59	0.16	0.16	0.08	0.08	0.40	0.41
	S41	0.26	0.26	0.10	0.10	0.59	0.60	0.24	0.24	0.08	0.08	0.50	0.49
	S42	0.37	0.37	0.12	0.12	0.65	0.66	0.20	0.20	0.07	0.07	0.43	0.44
	S43	0.40	0.39	0.13	0.13	0.63	0.65	0.32	0.32	0.09	0.09	0.53	0.53
	S44	0.45	0.44	0.15	0.15	0.71	0.74	0.26	0.25	0.09	0.09	0.57	0.58
Northwest	S45	0.11	0.11	0.09	0.09	0.28	0.29	0.12	0.11	0.06	0.06	0.29	0.30
	S46	0.37	0.38	0.17	0.17	0.57	0.57	0.23	0.28	0.10	0.10	0.40	0.34
	S47	0.15	0.15	0.08	0.08	0.38	0.38	0.10	0.10	0.04	0.04	0.25	0.25
	S48	0.25	0.25	0.13	0.13	0.58	0.57	0.13	0.13	0.07	0.07	0.36	0.35
	S49	2.45	2.08	0.10	0.10	0.51	0.85	0.96	0.90	0.07	0.07	0.21	0.22
	S50	0.25	0.25	0.10	0.10	0.50	0.50	0.09	0.09	0.04	0.04	0.29	0.29

MO = mean of 1-hour rainfall (observed data), ME = mean of 1-hour rainfall (NSRP model), KO = probability of 1-hour rainfall (observed data), KE = probability of 1- hour rainfall (NSRP model), KO2 = probability of 24-hour rainfall (observed data, KE2 = probability of 24- hour rainfall (NSRP model)

1-hour rainfall and the probabilities of the 1 and 24-hour rainfall estimated from the model are compared with these statistics values calculated from the observed data. Part of the results, focusing on the month of November and December only, is displayed in Table 3. It can be seen that there are no major differences between the estimated and the observed values of the statistics of interest.

CONCLUSION

The results of this study proved that the Neyman-Scott Rectangular Pulse (NSRP) model is able to imitate the pattern of actual rainfall in Peninsular Malaysia by comparing the parameters as well as the spatial distribution of the means and probabilities of 1 and 24-hour rain. Thus, results from the NSRP model fitting for each station are valid to be used in further analysis that is to evaluate the behavior of storm rainfall.

ACKNOWLEDGMENT

The authors are indebted to the staff of the Department of Irrigation and Drainage for providing hourly rainfall data to make this study possible. This research would not have been possible without the sponsorship from Universiti Kebangsaan Malaysia. This research was funded by UKM- DIP-2012-15.

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