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Homogeneity Test on Daily Rainfall Series for Malaysia

Norlee Hainie Ahmad and Sayang Mohd Deni
Centre for Statistical and Decision Science Studies, Faculty of Computer & Mathematical Sciences, 40450, UiTM Shah Alam, Selangor, Malaysia
e-mail: norlee_stats@yahoo.com , sayang@tmsk.uitm.edu.my

Abstract In this study, homogeneity tests have been applied at 76 meteorological stations in Peninsular Malaysia from 1975 to 2010 and also 7 stations in Sabah and Sarawak. A two-step approach is followed. First, four homogeneity tests, namely standard normal homogeneity test (SNHT), Buishand range test, Pettittt test, and von Neumann ratio tests are applied to evaluate the daily series. In order to evaluate the performance of the methods used, two testing variables i.e. annual rainfall amount and annual number of wet days with threshold 1mm are selected. After that, the results of the different tests are classified into three classes: 'useful', 'doubtful' and 'suspect'. Each test is evaluated separately and inhomogeneous stations are determined. By considering both of the testing variables, the result shows that 22% of the station series in Peninsular Malaysia are detected as inhomogeneous series and the remaining 59 stations which are equivalent to 78% are considered homogeneous. Meanwhile, for Sabah and Sarawak all stations or 100% are classified into homogenous series.

Keywords Homogeneity Tests; Standard Normal Homogeneity Test; Buishand Range Test; Pettitt Test; Von Neumann Ratio Test; Rainfall Amount Series; Wet Day Series.

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1 Introduction

The quality of the data leads to the accuracy and reliability of the particular model. In his study, Fatih et al. [1] stated that there are many chances of inhomogeneous observation records due to the method used, the conditions around the station and the reliability of the measurement tool and etc. Homogeneous climate series is defined as series which is only influenced by the climate changes. According to Suhaila et al.[2] measurements must be taken using the same instrument at the same time and day within the same environment so that the result will be only caused by the variations occur in the climate. Nevertheless, Khaliqa et al. [3] claimed that it is impossible to obtain the data without -challenges/obstacles due to station relocations, equipment changes, equipment drifts, changes in the method of data collection, and changes in the general surroundings of a station. Thus, before conducting any climatic analysis, the homogeneity of the series must be confirmed. Any inhomogeneous series must be detected, adjusted or removed from the analysis. For this reason, the data should be tested for reliability and homogeneity prior to their implementation in the research studies.

The homogeneity tests of time series can be classified into two groups, absolute method and relative method. The test is applied for each station separately in the former, while the neighboring stations are used in the latter. Generally, it is recommended by Peterson et al.[4] to apply homogeneity tests relatively. Wijngaard et al. [5] suggested if the two series are sufficiently correlated, relative tests are considered to be more powerful than absolute tests. As a result, inhomogeneities are more easily detected because of the climate variations. Even though relative tests are not able to deal with simultaneous changes happened at the reference station, relative testing is often being the first option. However, for amount rainfall series in Malaysia, relative testing is not appropriate since the rain gauge stations used are sparsely distributed as some are located in the rural, urban and mountainous areas while others are in coastal areas. Hence, each station may have a different surrounding area and different climatic environment. For that reason, Suhaila et al. [2] makes the point that it is quite impossible to find a neighboring station which could be a reference station. Therefore, the homogeneity analysis is restricted to absolute tests.

Many studies on homogeneity test have been done since 1990s. . In a research by Wijngaard et al [5], four homogeneity tests; SNHT, Buishand range (BR) test, Pettitt test and von Neumann ratio (VNR) test are employed to test the European climate. The results are classified into three classes; useful, doubtful and suspect depending on the number of tests rejecting the null hypothesis. Three testing variables are used, each consists of annual values. For temperature, the two testing variables are annual mean of diurnal temperature range and annual mean of the absolute day-to-day differences while for precipitation, the annual number of wet days (threshold 1mm) is employed.

Many countries have used the same homogeneities tests to detect the inhomogeneities of data. The research conducted by Fatih et al [1] for Turkish temperature employs an absolute test approach. Homogeneity tests are applied for testing the reliability of the data by using SNHT and Pettitt tests after calculating the annual mean temperature values from the monthly totals. They have concluded that SNHT and Pettitt tests are more sensitive in the determination of inhomogeneity in series and the results show that these methods can be used successfully in the homogeneity tests of temperature series.

A homogeneity test has become a vital preliminary procedure in analyzing the rainfall series in Malaysia. Conversely, most of the studies employ the methods proposed by Wijngaard et al [5] to check the homogeneity of the data. For instance, Kang and Fadhilah [6] determine the homogeneity of Damansara, Johor and Kelantan stations in Peninsular Malaysia by using three testing variables; annual mean, annual maximum and annual median. The same method is also employed by Suhaila et al [2] to test the daily rainfall series of Peninsular Malaysia from 1975 to 2004.

The main objective of this study is to detect any inhomogeneous rainfall series in Malaysian by adopting the two-way approach introduced by Wijngaard et al [5] where two testing variables; annual rainfall amount and annual wet days are used. Due to several circumstances, absolute tests need to be employed.

2 Data and Methodology

Data for daily rainfall from all stations are obtained from Drainage and Irrigation Department and Malaysian Meteorological Department. Data for Peninsular Malaysia are recorded from 1975 to 2010 whereas data for Sabah and Sarawak are documented from 1979 to 2009. Table 1 shows the stations for Sabah and Sarawak with their geographical coordinates while Figure 1 shows the map of Sabah and Sarawak along with all stations used in this study. For Peninsular Malaysia, Figure 2 and Table 2 (in appendix) show the details of each station. Most of the rainfall data used in the present study are recorded from the automatic recorded rain gauges where the data are normally measured using a tipping bucket rain gauge with a sensitivity of 0.5 mm per tip. In spite of all this, the data collection is still done manually for some stations. The daily rainfall amount for a particular day is the amount collected over the 24 hour period beginning from 0800 a.m. on that day. This procedure is the same for each manual operated station. Since there are different procedures used to collect the rainfall data, the homogeneity of each data series is conducted using the two-step approach introduced as implied by Wijngaard et al [5].

Table 1 The geographical coordinates of the rain gauge stations in Sabah and Sarawak.

No	Station Name	Longitude	Latitude
1	Kuching	1.5	110.3
2	Miri	4.3	113.9
3	Sibu	2.3	111.8
4	Bintulu	3.2	113.0
5	Kota Kinabalu	5.9	116.1
6	Sandakan	5.9	118.1
7	Labuan	5.2	115.2

Figure 1 Location of all stations in Sabah and Sarawak.

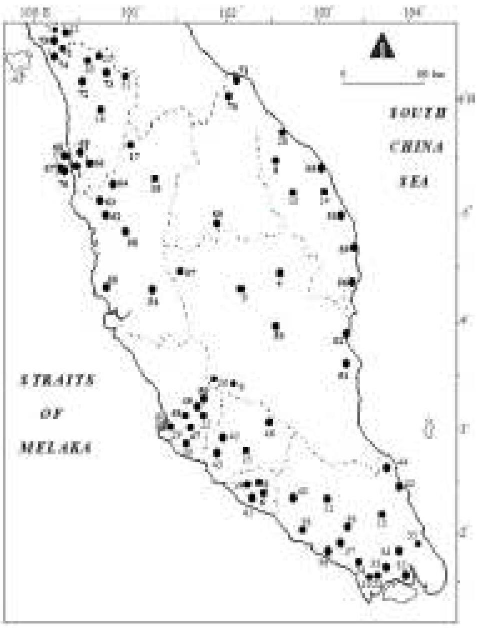

Figure 2 Location of all stations in Peninsular Malaysia

3 Statistical Methods

Four homogeneity tests which are Standard normal homogeneity test (SNHT), Buishand range (BR) test, Pettittt test, and von Neumann ratio (VNR) are used to test the homogeneity of the rainfall data. Null hypothesis Y_i (i =1, 2,...,n) is independent and identically distributed, where Y_i is the testing variable which could represent either the annual number of wet days or the annual rainfall amount that have the same mean is said to be homogeneous while alternative hypothesis SNHT, BR test and Pettittt test assume the series consisted of break in the mean and is considered as inhomogeneous. These three tests which are often called the "location-specific tests" as in Wijngaard et al [5] and capable to detect the year where break occurs. On the other hand, VNR cannot detect the year of the break because the series is not randomly distributed under alternative hypothesis. There are some differences between the first three tests above. SNHT is sensitive in detecting the breaks near the beginning and the end of the series whilst BR test and Pettittt test are used to identify the break in the middle of the series. Kang and Fadhilah [6] seek to identify that SNHT and BR tests assume Y_i to be normally distributed; however, Pettittt test does not need this assumption because it is a non-parametric rank test. Given that Y_i (i =1, 2,...,n) is the variable to be tested with $\bar{Y}$ and s as the mean and standard deviation respectively. The mathematical formulation of the four tests is given as below :

1. *Standard Normal Homogeneity Test*

A statistic $T(d)$ compares the mean of the first d years of the record with the last of *(n − d)* years which can be written as follow:

$$T_d = d\bar{z}_1^2 + (n-d)\bar{z}_2^2, d = 1,2,...,n$$

$$\bar{z}_1 = \frac{1}{d}\sum_{i=1}^{d}(Y_i - \bar{Y})/s \qquad \text{and} \qquad \bar{z}_2 = \frac{1}{n-d}\sum_{i=d+1}^{n}(Y_i - \bar{Y})/s$$

are the mean values of z_i during the first *d* years and the last (*n* - *d*) years respectively. A high *T* value in year *d* implies that a break is located in the year *d*. The test statistic T_0 is defined as :

$$T_0 = \max_{1 \le d \le 0} T(d)$$

The probability of rejecting the null hypothesis when T_0 exceeds a certain critical value is depended on the sample size. Then the series would be classified as inhomogeneous at a certain level; e.g. 95% level of significance.

2. *Buishand Range Test*

The homogeneity test can be based on the cumulative deviations from the mean or adjusted partial sums which are defined as:

$$S_0^* = 0 \qquad \text{and} \qquad S_d^* = \sum_{i=1}^{d}(Y_i - \bar{Y}), d = 1,2,....,n$$

For any homogeneous series, the values of S^* will fluctuate around zero since there is no systematic deviation of the Y_i values with respect to their mean will appear. On the other hand, the value of S_d^* could be a positive or negative shift if a break is present near the year *d*. Rescaled adjusted partial sums are obtained by dividing the values of S_d^* by the sample standard deviation, *s*. Because Buishand [7] indicate that the values are not influenced by any linear transformation, therefore it is suitable to use the homogeneity test.

The test is given as:

$$Q = \max_{0 \le d \le n} \left| S_d^* / s \right|$$

Another statistic test which could also be used is the range which computes the difference between the maximum and minimum value of the rescaled adjusted partial sums. The formula is given as follows:

$$R = \left(\max_{o \le d \le n} S_d^* - \min_{o \le d \le n} S_d^* \right) \Big/ s$$

Buishand [7] gives critical values for both homogeneity tests $Q/\sqrt{n}$ and $R/\sqrt{n}$.

3. Pettitt Test

This test is a non-parametric test which does not require any assumption of normality. The test is based on the ranking order of the Y_i values. The statistic is given as follows:

$$X_d = 2\sum_{i=1}^{d} r_i - d(n+1) \qquad d = 1,2,...,n$$

The break is detected near the year *m* given that

$$X_m = \max_{1 \le d \le n} \left| X_d \right|$$

4. Von Neumann ratio Test

The von Neumann ratio is defined as the ratio of the mean square successive difference between the years to the variance. The test statistic is given as follows:

$$V = \sum_{i=1}^{n-1} (Y_{i+1} - Y_i)^2 \Big/ \sum_{i=1}^{n} (Y_i - \overline{Y})^2$$

This statistic is often used to test the independence of the random variables *Yi,* which are assumed to be successive observations on a stationary Gaussian time series, and sometimes is used to test the stationarity of the mean for an uncorrelated time. However, this statistic can also be applied in detecting the inhomogeneous series. The series can be considered as homogeneous series if the expected value, *E[V]*=2. But for inhomogeneous series, Buishand [7] agreed that the value of *V* tends to be lower than 2. On the other hand, the value greater than 2 implies that the series has rapid variations or oscillations in the mean as mentioned in Suhaila et al. [2] by Bingham and Nelson, 1981.

3.1 Evaluation Of The Tests

The second step in this study is an overall evaluation of the four tests. The outcomes of the four tests for annual rainfall amount and annual wet days are grouped together. A classification is made depending on the number of tests rejecting the null hypothesis.

(a) Class A: Useful

The series that rejects one or none null hypothesis under the four tests at 1% significance level are considered. Under this class, the series is grouped as homogeneous and can be used for further analysis.

(b) Class B: Doubtful

The series that reject two null hypotheses of the four tests at 1% significance level is placed in this class. In this class, the series have the inhomogeneous signal and should be critically inspected before further analysis.

(c) Class C: Suspect

When there are three or all tests are rejecting the null hypothesis at 1% significance level, then the series is classified into this category. In this category, the series can be deleted or ignored before further analysis.

In this study, for the stations that are classified into "suspect' will be exclude and with no corrections because a very careful approach is needed to adjust the data.

4 Results and Discussion

Annual rainfall amount and annual number of wet day of each station are tested by the four homogeneity tests. Figure 3 shows the results of the SNHT applied to the rainfall series for Station 38 with the annual rainfall amount as the testing variable, while Fig. 4 shows the results of the SNHT applied to the rainfall series for the same station with the annual number of wet days as the testing variable

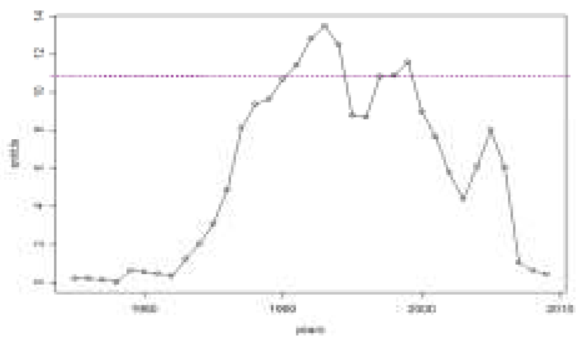

Figure 3 The result of SNHT applied to the annual rainfall amount at station 38

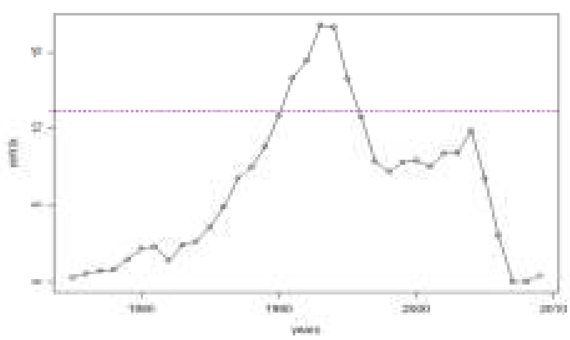

Figure 4 The result of SNHT as applied to the annual number of wet days at station 38.

The red line shows the critical values for both tests.

In the first case, the homogeneity tests are applied to the series of annual rainfall amount. The SNHT clearly detects an inhomogeneity at the 1% level around year 1993. The other two tests, BRT and Pettitt test are also significant at the 1% level. Therefore, the series of Station 38 is labeled as 'suspect' since three tests rejected the null hypothesis at the 1% level of significance. While in the second case, the SNHT is applied to the series of wet days and the results are depicted in Fig. 4. A break is present in the year around 1993. Again the other two tests, BRT and Pettitt reject the null hypothesis at the 1% level of significance. Thus, this series is labeled as 'suspect' and this station will be deleted for the next analysis. Table 3 shows the result for all test applied at station 38 with the 1% critical values for each test.

Table 4 shows the inhomogeneous station by using annual rainfall series and annual wet day at all stations. In the first case, the homogeneity tests are applied to the series of rainfall amount followed by the series of wet day. Critical values taken from Wijngaard et al [5] for SNHT, BR test, Pettitt test and VNR test are 10.79, 1.724, 178 and 1.254 respectively. In this study, no attempt is made to correct or adjust the daily series since a very careful approach is needed. Therefore, this study chooses to exclude those stations which resulted in inhomogeneities in the data series.

Table 4 Inhomogeneous stations in Peninsular Malaysia

Rainfall amount series				Wet day series			
Break year(test statistic)				Break year (test statistic)			
No.	SNHT	BRT	Pettitt	No.	SNHT	BRT	Pettitt
s6	12.97	1.96	227	s5	12.01	2.27	180
s33	19.95	2.02	268	s12	14.77	2.02	247
s38	13.52	1.94	239	s16	12.61	1.85	245
s66	23.16	2.41	308	s23	21.19	2.17	275
s69	11.88	1.83	223	s27	12.49	2.03	196
				s31	24.58	2.42	310
				s32	19.95	1.80	194
				s38	16.81	2.03	290
				s40	12.50	1.88	236
				s44	18.14	2.17	265
				s46	22.81	1.86	215
				s54	11.12	1.85	217
				s63	16.70	2.18	248

Table 3 Result for station 38

Wet days series				
Station	**snhtT0**	**BuishR.CV**	**Pettit**	**Von NR**
38	16.813	2.027	290	0.766
Rainfall amount series				
38	13.52	1.94	239	0.89
Critical Value (1%)	10.79	1.724	178	1.254

Table 5 Number and percentage of rainfall stations which are classified into three categories; 'useful', 'doubtful' and 'suspect'.

Series	Class A Useful	Class B Doubtful	Class C Suspect
Rainfall amount	65 (85.53%)	6 (7.89%)	5 (6.58%)
Wet days	53 (69.74%)	10 (13.16%)	13(17.11%)

Figure 5 maps the overall test results for the series of rainfall amount. The rainfall series for the majority of rain gauge stations are labeled 'useful' which is 65 percent. All three location-specific tests reject the null hypothesis at 1% level for 5 stations as shown in Table 5 which indicate that an inhomogeneity is detected in the series for these stations. Six stations are labeled as 'doubtful' with 7.9%. An interesting result is the rainfall amount series of all rain gauge stations in the east coast of Peninsular Malaysia are sufficiently homogeneous for next analyses. By means, there is no clear signal that an inhomogeneity in the amount series is present for these stations. In addition, the eastern area of Peninsular Malaysia is less developed compared to the western area. Therefore, there are possibilities that no large impact in the changes of environmental characteristics is detected for the eastern stations, Suhaila et al [2]. Figure 6 shows the results for the series of wet days. More stations are suspected in detecting inhomegeneities in the series of wet days than rainfall amount series. 53% of the series are labeled as "useful" followed by 10% as 'doubtful' while 13% of the series are declared as 'suspect'. The suspect stations are scattered across the region.

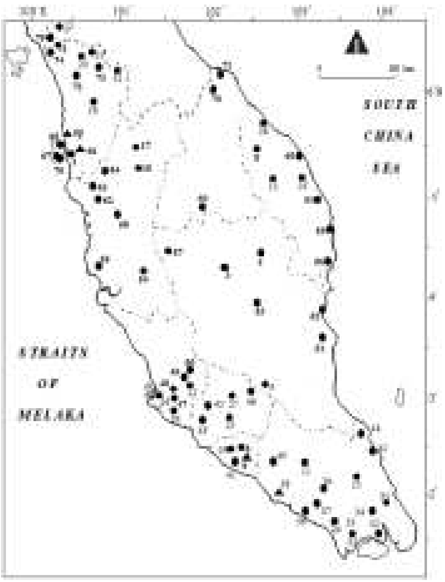

Figure 5 Test results for the rainfall amount series as the testing variable. (● useful ◆ doubtful ▲ suspect)

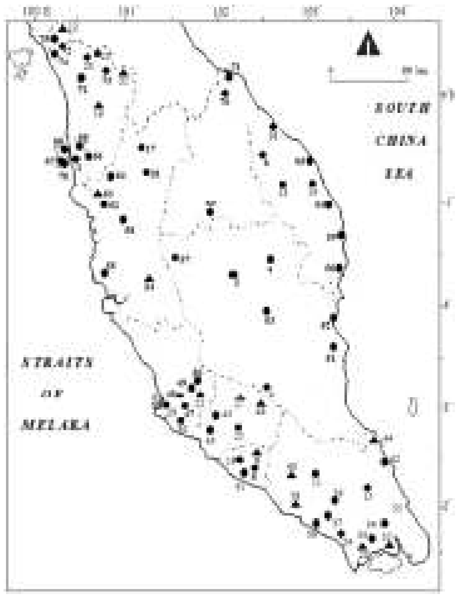

Figure 6 Test results for the wet days series as the testing variable. (● useful ◆ doubtful ▲ suspect)

For Sabah and Sarawak the result shows that all stations are doubtful for both testing variables. That means 100% of the series are labeled 'doubtful'. Figure 7 maps the overall test results for the series of rainfall amount combined with wetdays followed by Table 6 that indicate the percentage of each class in Sabah and Sarawak.

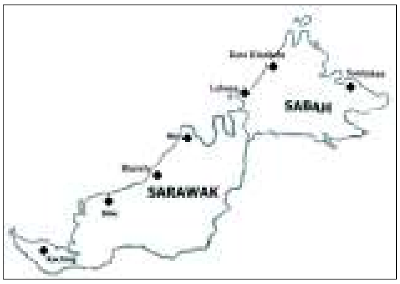

Figure 7 Test results for the rainfall amount series and wetdays as the testing variables. (● useful ◆ doubtful ▲ suspect)

Table 6 Number and percentage of rainfall stations which are classified into three categories; 'useful', 'doubtful' and 'suspect'.

Series	Class A Useful	Class B Doubtful	Class C Suspect
Rainfall amount	0 (0%)	7 (100%)	0 (0%)
Wet days	0 (0%)	7 (100%)	0 (0%)

6 Conclusion

The aim of this study is to detect any inhomogeneous series for the Peninsular Malaysian rainfall data using four homogeneity tests. This approach is adopted from Wijngaard et al [2].The absolute tests are chose rather than the relative tests since the stations in Peninsular Malaysia are sparsely distributed. Besides, to find a homogeneous neighboring station is quite impossible in this study. The SNHT, BRT, Pettitt test and VNRT are the four tests which are applied to the series. Annual rainfall amount and annual wet days using 1mm threshold are used as the testing variables. The result shows different results of inhomogeneous stations for both testing variables. Nonetheless, break in the series point to the same year for station 38. Of all stations, 17 stations are detected inhomogeneous. Therefore, all 17 stations should be excluded in the next analysis. Adjustments can be made to inhomogeneous series in order to improve it but then again, a procedure to adjust or correct the inhomogeneous series needs a very vigilant approach. In addition, the reasons that cause the break should be clearly identified before any action can be taken. So as an alternative, all series that are labeled 'suspect' are removed from the study for the time being until the real reasons that cause the break are identified.

Acknowledgement

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Appendix

Table 2 : The geographical coordinates of the rain gauge stations

Bil	District	longitude	latitude	Bil	District	longitude	latitude
1	Pintu A.Bagan,Air Itam	100.2	5.35	39	Kluang	103.32	2.02
2	Arau	100.27	6.43	40	Tangkak	102.57	2.25
3	S. K. Kg. Aur Gading	101.92	4.35	41	Malacca	102.25	2.27
4	Ldg. Batu Kawan	100.43	5.26	42	Mersing	103.83	2.45
5	Ldg. Bkt. Asahan	102.55	2.39	43	Hospital Port Dickson	101.8	2.53
6	Kg. Chebong	102.35	4.12	44	Endau	103.67	2.59
7	Guar Nangka	100.28	6.48	45	Setor JPS Sikamat Seremban	101.96	2.74
8	Klinik Bidan,Jambu Bongkok	103.35	4.94	46	Sg.Lui Halt	102.37	3.08
9	Janda Baik	101.86	3.33	47	Petaling Jaya	101.65	3.1
10	Jam. Sg. Simpangn ,Jln. Empat	102.19	2.44	48	Subang	101.55	3.12
11	Ibu Bekalan Kahang , Kluang	103.6	2.23	49	Empangan Genting Kelang	101.75	3.24
12	Kaki Bukit	100.21	6.64	50	Gombak	101.73	3.27
13	Sek. Keb. Kemasek	103.45	4.43	51	Rumah Pam Pahang Tua,Pekan	103.36	3.56
14	Sek. Keb. Kg. Jabi	102.56	5.68	52	Kuantan	103.22	3.78
15	Ldg. Kian Hoe , Kluang	103.27	2.03	53	Rumah Pam Paya Kangsar	102.43	3.9
16	Kodiang	100.3	6.37	54	Rumah Kerajaan JPS,Chui Chak	101.17	4.05
17	Dispensari Kroh	101	5.71	55	Sitiawan	100.7	4.22
18	Stn. Pemereksaan Hutan, Lawin	101.06	5.3	56	JPS Kemaman	103.42	4.23
19	Pekan Merlimau	102.43	2.15	57	Ldg Boh	101.43	4.45
20	Rumah Penjaga Jps. Parit Nibong	100.51	5.13	58	Ipoh	101.1	4.57
21	Pendang	100.48	5.99	59	Sek.Men. Sultan Omar, Dungun	103.42	4.76
22	JPS Wilayah Persekutu	101.68	3.16	60	Gua Musang	101.97	4.88
23	Ldg. Getah Kukup , Pontian	103.46	1.35	61	Kg. Menerong	103.06	4.94
24	Ldg. Benut ,Rengam	103.35	1.84	62	Pusat Kesihatan Bt.Kurau	100.8	4.98
25	Ldg. Sg. Sabaling	102.49	2.85	63	Rumah JPS, Alor Pongsu	100.59	5.05
26	Genting Sempah	101.77	3.37	64	Selama	100.7	5.14
27	Ldg. Sengkang	101.96	2.43	65	Stor JPS Kuala Trengganu	103.13	5.32
28	Kg. Merang ,Setiu	102.95	5.53	66	Bkt Berapit	100.48	5.38
29	Ibu Bekalan Sg. Bernam	101.35	3.7	67	Kolam Takongan Air Itam	100.27	5.4
30	Kg. Sg. Tua	101.69	3.27	68	Klinik Bkt. Bendera	100.27	5.42
31	Sik	100.73	5.81	69	Rumah Pam Bumbong Lima	100.44	5.56
32	Stor JPS Johor Bahru	103.75	1.47	70	To' Uban	102.14	5.97
33	Pintu Kawalan Tampok Batu Pahat	103.2	1.63	71	Kota Bharu	102.28	6.17
34	Senai	103.67	1.63	72	Alor Star	100.4	6.2
35	Sek.Men.Bkt Besar Di Kota Tinggi	103.72	1.76	73	Ampang Pedu	100.77	6.24
36	Sek.Men.Inggeris Batu Pahat	102.98	1.87	74	Padang Katong ,Kangar	100.19	6.45
37	Pintu Kawalan Sembrong	103.05	1.88	75	Abi Kg. Bahru	100.18	6.51
38	Pintu Kawalan Separap Batu Pahat	102.88	1.92	76	Bayan Lepas	100.26	5.3