Urban Rainfall-Runoff Study to Validate the Design Chart in the Malaysian Urban Stormwater Management Manual (MSMA)

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ABSTRACT

Knowledge on rainfall-runoff response is vital in engineering practices for developing area in the humid tropics. This paper will discuss the runoff response due to varying rainfall within small Malaysian urban catchment. The 10-min intervals rainfall and runoff data ranging from year 1996 to 2004 had been utilized and only 104 events were suitable for detail analysis. Firstly, a relationship between direct runoff and the mean areal rainfall was developed and validated using statistical model. To verify the representativeness of rainfall-runoff response, rainfall concentration between developed area and suburban/rural area was predetermined. The 95 % confidence limit shows that the determined initial loss from urban rainfall-runoff relationship varied between 5 to 10 mm for Sg. Kayu Ara catchment. The correlation between runoff coefficients and rainfall intensities was then determined. The detail analysis highlighted that the correlation between runoff coefficients and rainfall intensities in the MSMA Design Chart 14.3 corresponded quite well with the degree of land use covers. This implies that the runoff coefficient versus intensity chart adopted from the Australian Rainfall and Runoff (1977) in the MSMA is in the suitable range for use in Malaysian urban condition.

KEYWORDS
Rainfall-Runoff Response, Runoff Characteristic, Urbanization Impact

INTRODUCTION

High intensity and long duration rainfall events are common in the humid tropic region as in Malaysian urban cities. This phenomenon is formed mostly through convective process (Embi and Mohd. Dom, 2004). The frequent occurrence of flash flood in the last several years especially within urban cities and town areas DID (2004) has initiate awareness to better understanding of urban stormwater management system. As reported by Desa et al. (2005), the highest 5-min point intensity storm event in year 2003 was 222 mm/hr and the rain lasted for 114 minutes which occurred in an urbanized Kerayong catchment, Kuala Lumpur.

The Malaysian Government, through the Department of Irrigation and Drainage Malaysia, has developed and implemented a comprehensive Malaysian Urban Stormwater Management Manual (DID, 2000) that normally call the MSMA (environmentally friendly drainage manual) to provide guidelines on how to manage urban stormwater system. However, due to the lack of local and regional data, several aspects were based on the standard codes of practice in overseas. For examples, the curves Design Chart 14.3 in MSMA for various land uses were adopted based on rainfall and runoff records in Australian. Thus, the main purpose this study is to determine the characteristic of Malaysia (humid tropic condition) urban rainfall-runoff and to validate the use of the MSMA curve in the practical design.

STUDY AREA

Geographically, the Sungai Kayu Ara catchment is located within N 3^0 $6'$ to N 3^0 $12'$ and E 101^0 $35'$ to E 101^0 $39'$ in Damansara, Kuala Lumpur as shown in Figure 1. The Sungai Kayu Ara catchment covers an area of 22.33 km^2, with Sungai Kayu Ara being the main river which is measured of 9.8 km in length. The river originates from the forest reserved highlands of Penchala and continues to flow toward southwest direction to the suburban area comprising Desa Sakti, Kampung Sungai Penchala and Taman Tun Dr. Ismail. Then, the flow stretches to the relatively flatten developed area until water level station No.3111404 (i.e. WL 4) which nears the confluence of Sungai Damansara.

The Sungai Kayu Ara catchment was selected because of several reasons. It is a well developed urban area with different land uses that enables to assess the MSMA design curves. Secondly, it has a dense network of automatic rainfall stations (11 stations) and a water level station as shown in Table 1. The overall rainfall density in the study catchment is about 0.5 /km^2 A continuous automated rainfall and water level data had been monitored for more than 10 years (since 1996). As suggested by Linsley et al. (1975), for an experimental catchment, the minimum requirement of station is 1 per 25 km^2. Thirdly, the stage-discharge curve had been developed by the Department of Irrigation and Drainage (DID), Malaysia recently. Finally, land uses and topographic in digital format of the catchment area is available information for use (by the Department of Survey and Mapping, Malaysia edited in 2002).

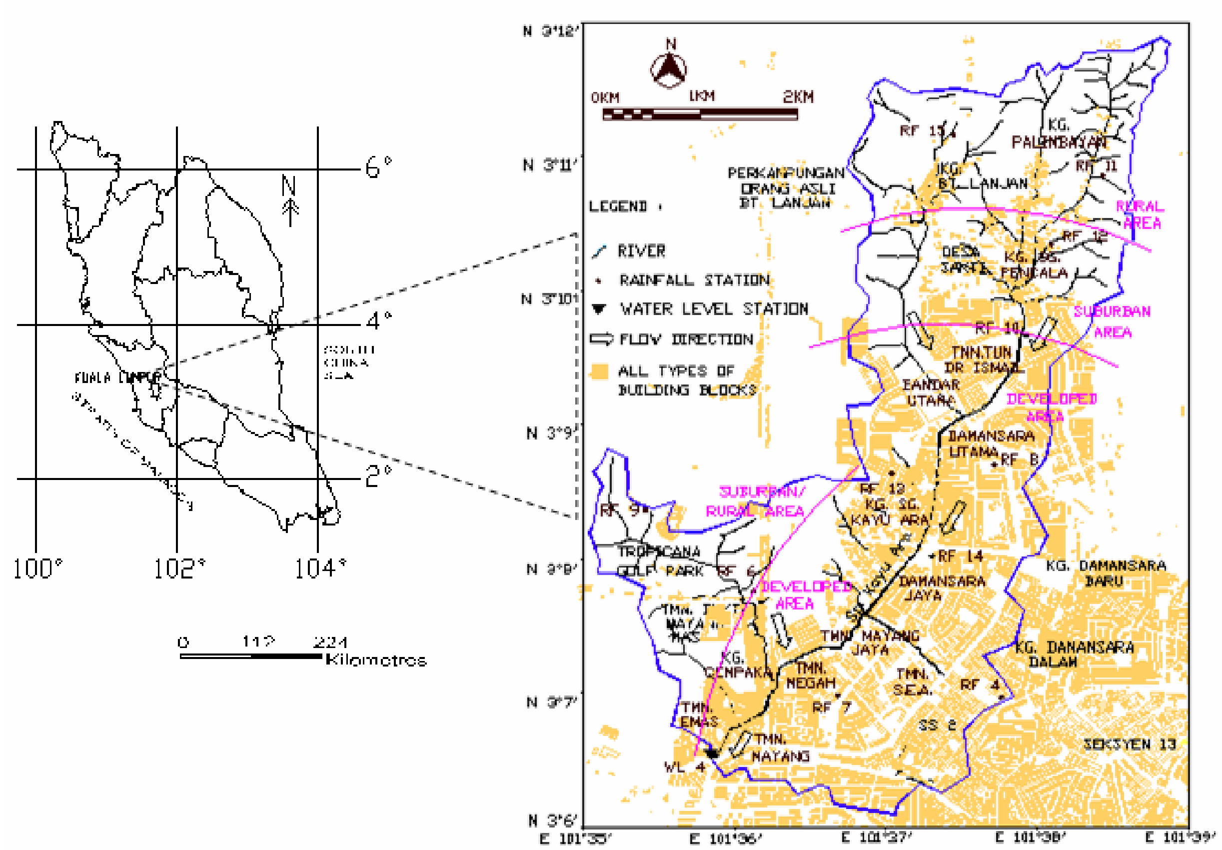

Figure 1: Location of study area and delineation of the Sungai Kayu Ara catchment

Table 1: Inventory information of hydrological stations in the Sungai Kayu Ara catchment

No.	Station No.	Location	Reference Code of Data Logger (Description)	
1	3110004	Balai Polis Sea Park	RF 60000407	Downloaded at fortnitely basis by the DID Staff
2	3110006	Tmn. Bukit Mayang Mas	RF 60000352	
3	3110007	Sek. Ren. Yuk Chai	RF 60000146	
4	3110008	Sek. Ren. Damansara Utama	N / A	
5	3110009	Tropicana Golf Resort	RF 60000353	
6	3110010	Balai Polis Tmn. Tun Dr. Ismail	RF 60000263	
7	3110011	Sungai Penchala Upstream	RF 60000150	
8	3110012	Masjid Jamek Sungai Penchala	RF 60000328	
9	3110013	TNB Bandar Utama	RF 60000132	
10	3110014	Sek. Men. Damansara Jaya	RF 60000327	
11	3110015	Lebuhraya Bukit Lanjan	RF 60000137	
12	3111404	Sungai Kayu Ara	WL 60000053	Telemetry

METHODOLOGY

Rainfall and water level data of 10 minutes intervals from 1996 to 2006 were retrieved from the DID Hydrology Unit. Subject to the limitations and data gaps of the records, only 104 events over the ten years' period (i.e. year 1996 – 2006) were considered suitable for further analysis. The selected events were based on these factors:

- There is no significant influence by antecedent rainfall that causes termendous increment of water level for at least 12 hours. An urban catchment was only considered to become wet if there was rainfall exceeding 5 mm within 24 hours in Australia (Abustan and Ball, 2000).

- There are only a single peak hydrograph were analyzed in order to ease the derivation of hydrological loss and to ensure a reliable estimate.
- The calculated direct runoff volume should exceed 3.0 mm. and at least six rainfall stations within the catchment were recorded rainfall event that triggered runoff.

In this study, a baseflow separation technique using the straight line method in order to determine the direct runoff volume (Chow et al, 1988). A straight line was plotted from the start of rise of discharge and extended to the point in recession limb until no more significant decrease in the following time steps. It is expected that the groundwater recharge and interflow induced during rainfall to be low and thus, will have less significant impact on the tail of discharge hydrograph (Abustan, 1997).

The mean areal rainfall was computed using the isohyetal method with the aids of Surfer® and the digital map. The isohyetal mean was used because it provided a more reliable estimate of rainfall depth by taking into account orograhic effect and storm morphology over the terrains (McCuen. 1989). This is important in determining proper estimate of direct runoff depth by dividing the direct runoff volume with rainfall of the entire catchment area. In this study, the runoff coefficient, C, was obtained through the ratio of direct runoff depth to mean areal rainfall (Institution of Engineers Australia, 1989).

As displayed in Figure 3, the delineation of sub-area was each determined using AutoCAD®. According to McCuen (1989), total rainfall over all sub-areas of different delineation equaled the isohyetal mean for entire catchment. The relationship between sub-area rainfall and mean areal rainfall is derived from the Equation (1) and (2).

Mean areal rainfall, $P = W_r P_r + W_u P_u$

Equation (1)

Rainfall concentration overdeveloped area (Sub-area 2), $F_u = \frac{W_u P_u}{P}$

Equation (2)

where, W_r = Fraction of sub-area 1 covering rural residential, cultivated land, park, shrub & highlands

= 0.45

W_u = Fraction of sub-area 2 covering urban residential, CBD, squatter area, cleared land and utilities

= 0.55

P_r = Mean areal rainfall over Sub-area 1

P_u = Mean areal rainfall over Sub-area 2

RESULTS AND DISCUSSIONS

RAINFALL-RUNOFF RESPONSE

Long term mean annual precipitation for each station, excluding station No.3110012, was obtained through the average of annual precipitations from the year 1996 until 2006 as shown in Figure 4. It was found that the average value of long term mean annual precipitation for the entire Sungai Kayu Ara catchment was 2296 mm. This value is very close to the long term mean annual record at Kuala Lumpur which was estimated at 2295.85 mm by Desa et al. (1996) from the year 1982 to 1992. This is probably due to the location of Kuala Lumpur which is merely within 15 to 20 km distance from this study area.

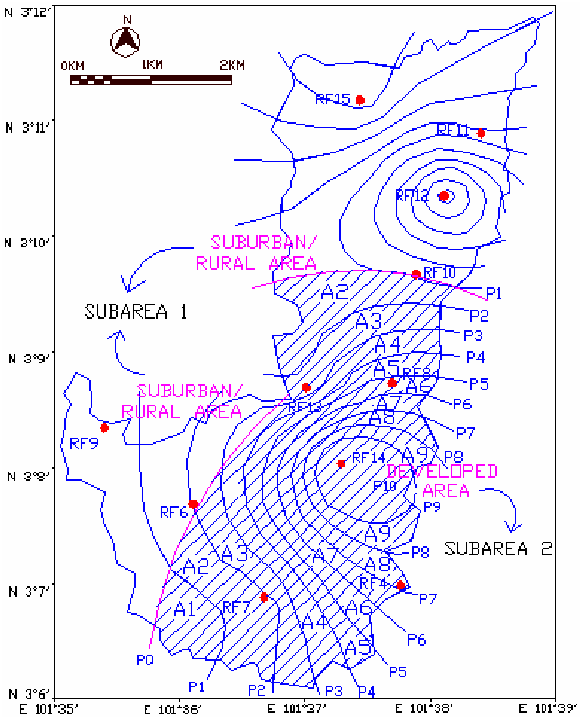

Figure 3: Estimation of isohyetal areal rainfall

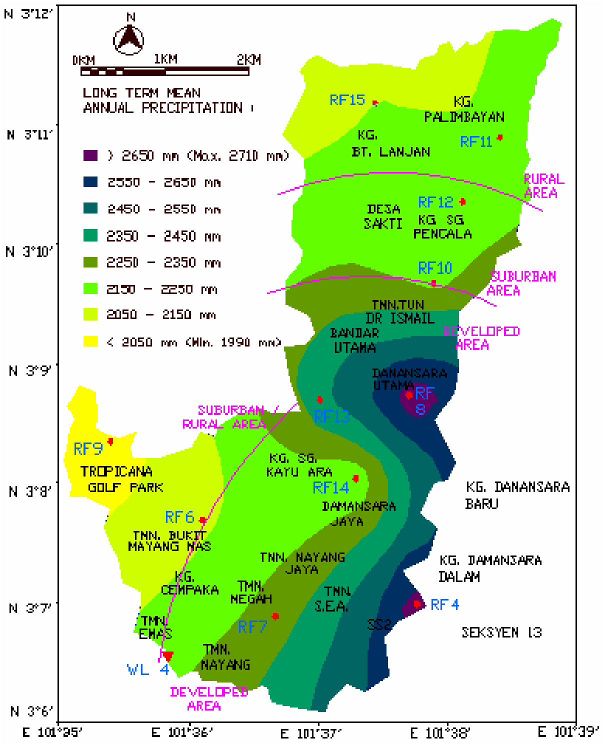

Figure 4: Variation in precipitation (1996 to 2004)

As shown in Figure 3, using the one dimensional regression method, the rainfall-runoff relationship for the Sungai Kayu Ara catchment was found to be R = 0.612P – 2.94 from the 104 events studied with the coefficient of determination (r^2 *linear*) of 0.843. The significance p-value was found to be 0.0001 (i.e. less than 0.05). This implies that the urban rainfall-runoff characteristics described by the model was statistically significant. From the analysis of hydrograph and hyetograph sets for the 104 events showed that the discharge would start rising drastically as soon as rainfall volume had reached 5 mm and higher.

From the Figure 5, the slope of plot could be implied as hydrological reduction factor (Harremoës and Arnbjerg-Nielsen, 1996). The interception on x-axis as the estimation of initial loss, or sometimes regard as the depression loss (Huber and Dickinson, 1988). Further analysis found that the regression slope was 0.612 with the 95 % confidence limits. The estimated initial loss would be about 2.93 mm. This finding is quite similar with the maximum depression loss and initial abstraction in other studies in urban areas (Viessmann, 1968; Tholin and Keifer, 1960). If compare to the Table 14.4 of MSMA which was adopted from SWMM Manual (DID, 2000), the estimated initial losses was slightly less double the value of 1.5 mm initial loss of impervious area.

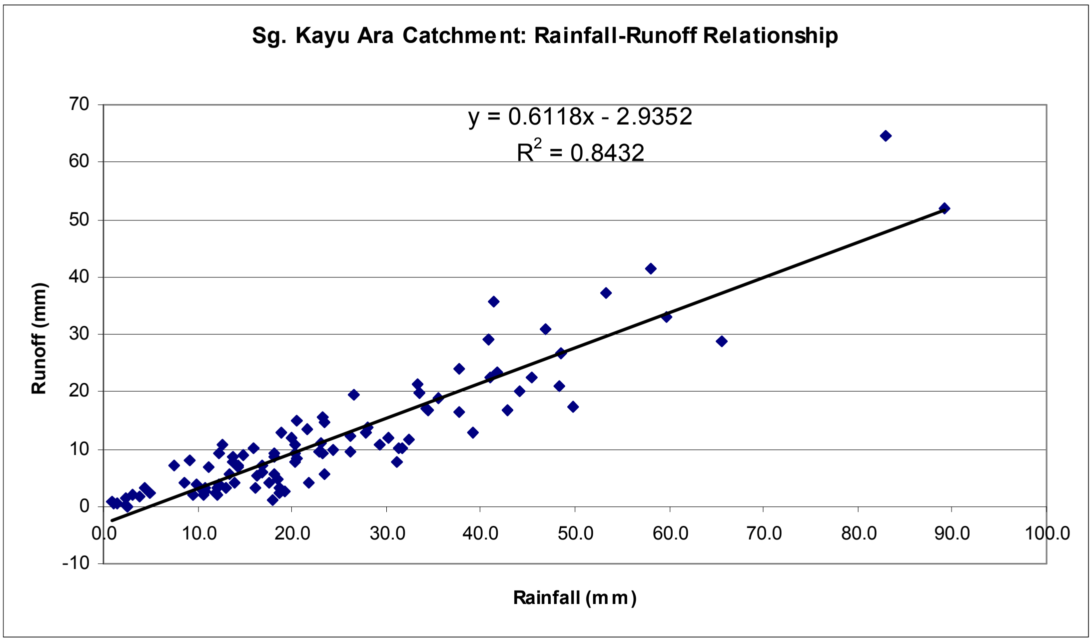

Figure 5: Urban rainfall-runoff relationship for the Sungai Kayu Ara catchment

The slope of regression plot can be interpreted as the percentage of impervious area according to Abustan and Ball (2000). Hence, the degree of overall imperviousness at Sungai Kayu Ara catchment was estimated at 61.2 %. However, the estimated percentage of land uses estimated from the digital topographic map was found to be 60.9 % as shown in Figure 5 and Table 2. The small discrepancy indicated that both methods could be utilized to estimate the generated runoff of total catchment area.

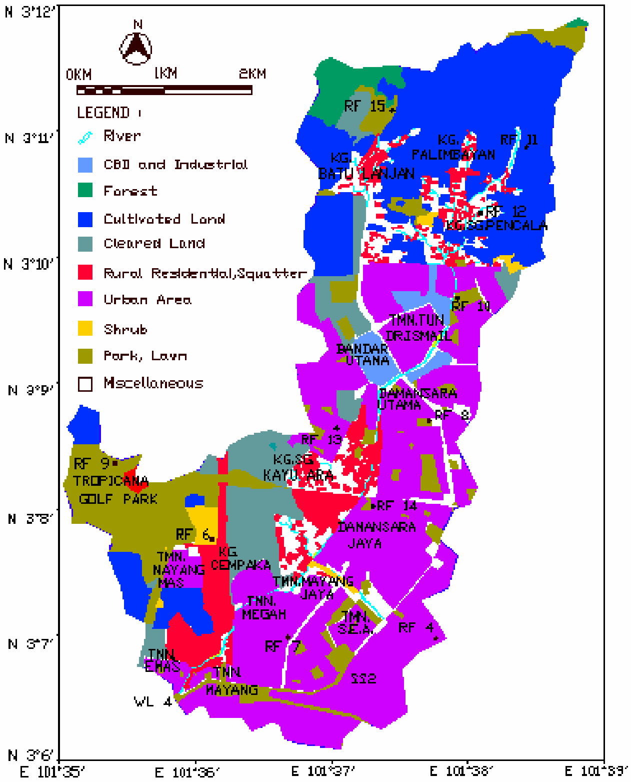

Figure 5: Classification of land use for Sungai Kayu Ara catchment

Table 2: The calculated estimation of land use types for Sungai Kayu Ara catchment

No.	Type of Land Use	Area (m^2)	Coverage (%)
1	Rural Residential, Squatter	1538554	6.9
2	Urban Residential	11165123	50.0
3	CBD	1116512	5.0
4	Cultivated Land	3126234	14.0
5	Cleared Land	1632341	7.3
6	Forest	372915	1.7
7	Park, Lawn	1860109	8.3
8	Shrub	194273	0.9
9	Miscellaneous	1324184	5.9
	TOTAL	22330245	100.0

ASSESSMENT OF MSMA DESIGN CURVES

Analyses on rainfall-runoff relationship and the high rainfall concentration over developed area (F_u) had validated the usage of selected rainfall events in explaining the actual urban rainfall-runoff response. The highest average total 10-min intensities had been identified for use in representing the generation of direct runoff via the preceding constant loss rate analysis. As shown in Figure 6, the 104 observed data points were scattered. This clearly showed that the runoff coefficient was subjected to integrated effects of rainfall intensity and its degree of concentration. The runoff coefficient was expected to be higher when there was more rainfall volume over the developed area, compared to suburban/rural area.

As shown in Figure 6, it can be implied that the design curve No 2 which indicated the poor paved and commercial areas should be used in design of this catchment since of the observed points lay below this envelope curve. Even though as discovered previously, estimated only 62% of the catchment gives direct respond to the rainfall events.

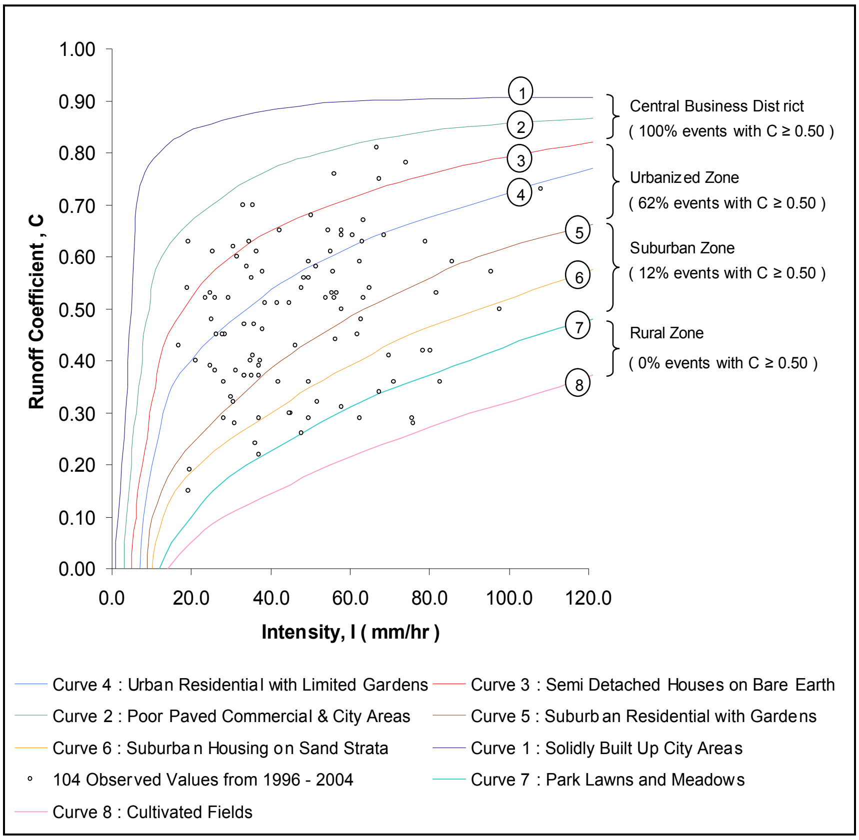

Figure 6: Assessment of the eight MSMA design curves (DID, 2000) using the local observed urban rainfall-runoff characteristics

CONCLUSION

A number of conclusions can be drawn from the findings of this study.

- The isohyetal mean rainfall could be determined with the utilization of l topographic digital map and time series hydrological data,. The isohyetal method is proven to provide more comprehensive analysis as it takes into account both orograhic effect and storm morphology over the terrains.
- The analysis of the best fitted urban rainfall-runoff relationship for the Sungai Kayu Ara catchment showed that the overall degree of catchment imperviousness was 61.2 % with initial loss of 2.94 mm. This finding validates the method used to measure the overall degree of catchment imperviousness. The visual estimation of digital topographic map and the Google Earth provided further support.
- The assessment of the MSMA curve indicates that the overall catchment of Sg Ara with multiple development can be categorized as the design curve No 2 which indicated the poor paved and commercial areas . This conclusion was based on the 104 observed events studied through the plotting of observed runoff coefficients of the highest average totaled 10-min intensities.

It should be noted that the study of rainfall-runoff is very site specific, thus, any application for similar type of landuses for different catchment should be handled with care. However, more case studies are recommended to be carried out to provide further support on this initial study. With more supporting evidences, a detailed curve for individual catchment response could be established nation wide.

ACKNOWLEDGEMENT

The authors wish to thank the Department of Irrigation and Drainage, the Department of Survey and Mapping Malaysia for providing valuable source of data and technical assistance. Furthermore, deepest appreciation goes to IRPA grant (Project No.02-03-08-0001-EA001) provided by the Ministry of Science, Technology and Innovation, Malaysia and the other team members in the IRPA grant.

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