

Infiltration Study for Urban Soil: Case Study of Sungai Kedah Ungauged Catchment

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Abstract: The DID (Department of Irrigation and Drainage) in Malaysia has produced a manual on urban stormwater management specifically for the Malaysia region with usage of infiltration method towards controlling the quantity and quality of surface runoff. With this method, the volume of surface runoff can be reduced and flood problems in major cities can be eliminated. The study areas of Sungai Kedah ungauged catchment are located at the northern region of Malaysia. The Kota Setar sub-catchment is located at the downstream of Sungai Kedah with the newly completed development of control barrage at the upper Kota Setar. This paper will describe the analyses of the infiltration curves at Kota Setar. The resulting infiltration maps have developed based on the infiltration capacities.

Key words: Sungai Kedah ungauged catchment, type of soil, infiltration curve, infiltration map.

1. Introduction

Undeveloped land has a little surface runoff, due to most precipitation infiltrate into the topsoil and the occurrence of hydraulic conductivity flow through as interflow into stream [1]. As a result of this process, the precipitation effects are averaged out over a long period of time (Fig. 1). However, as the catchment develops and land which is covered with an impermeable surface (e.g., roads, roofs, parking bays, and pedestrian walks) will result as a deeper surface runoff, this will result in the changes in hydrological cycle. This makes the proportion of evapo-transpiration, runoff and infiltration of precipitation change. The control at source approach, as been mentioned in MSMA (Manual Mesra Alam) 2nd edition 2011, is used for water balance by enhanced infiltration of the water into the ground. For a soil to be suitable for enhanced infiltration, it must, in particular, be permeable and unsaturated. This research is done at Sungai Kedah catchment to determine the infiltration curve and soil permeability.

2. Study Area

The study area, Sungai Kedah catchment, is located at the northern region of Malaysia as shown in Fig. 2.

The nonlinear rainfall-runoff model [2] has been applied to the Sungai Kedah catchment, which is located in the northern region of Malaysia. The catchment, which is ungauged, consists of 45 sub-catchments of which the Kota Setar sub-catchment is part of it. The Kota Setar sub-catchment is approximately 624 km² and has a semi-arid climate, which is subject to heavy rainfall during the months of September to March. Within this sub-catchment, there is the Kota Setar rainfall station (ID 6103047) (06°06'52" N; 100°21'57.4" E) that gathers rainfall and stream flow data. In addition to this station, data can be obtained from seven other gauged stations, which are Sungai Kedah (6103047) (06°06'52" N; 100°21'57.4" E); Klinik Jerniang (5606066) (05°48'50.5" N; 100°38'48" E); Kompleks Rumah Muda (6108001) (06°06'09.1" N; 100°50'27.7" E); Ampang Pedu (6207032) (06°14'34" N; 100°45'31" E); Padang Sanai (6306031) (06°20'30" N; 100°41'15.5" E); Kuala Nerang (6206035) (06°14'30.2" N; 100°34'16.3" E) and Sungai Bata (06°17'00.2" N; 100°25'51.2" E). Although the average

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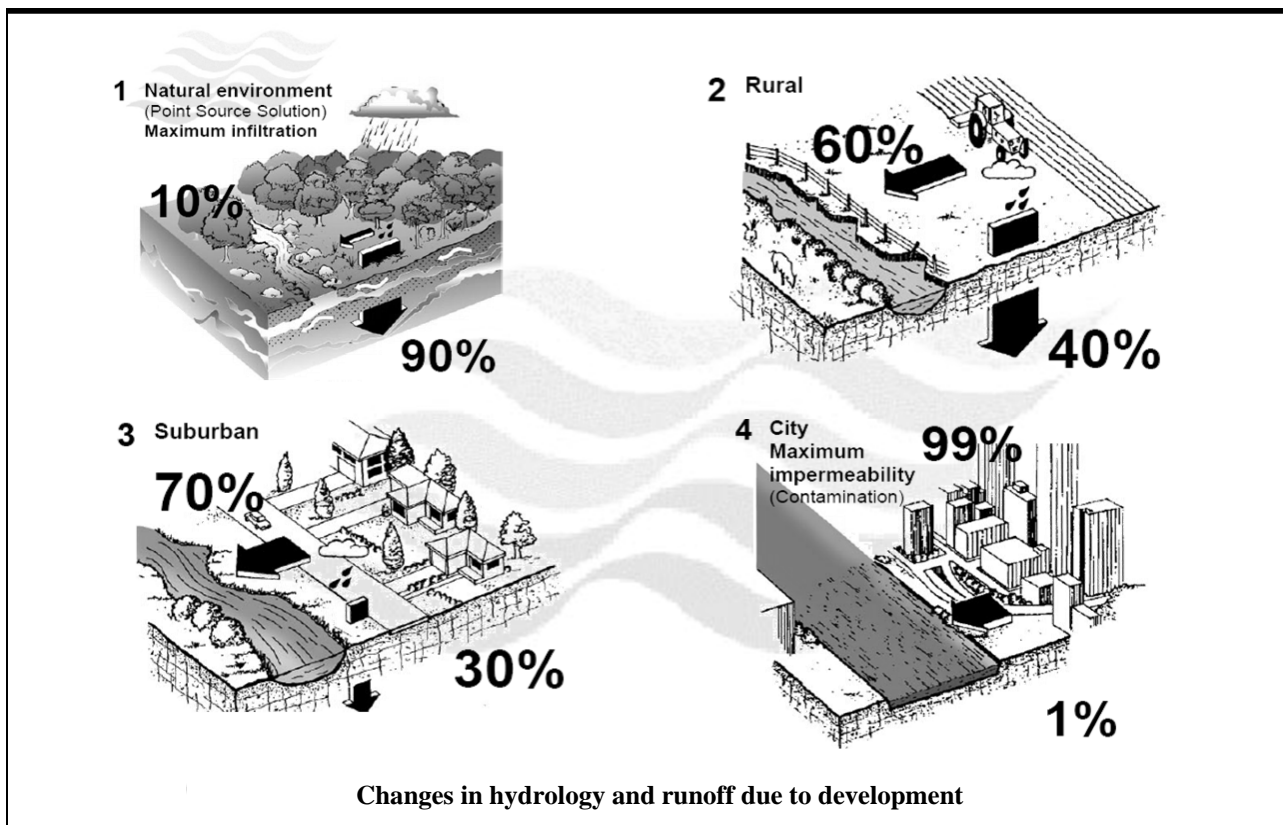


Fig. 1 Impacts of urbanization on hydrology.

Source: Department of Irrigation and Drainage MSMA Manual 2011.

rainfall distribution over the Kota Setar sub-catchment (Kota Setar District 1) can be uniformly determined using the Thiessen polygon model, the readings and output from the stations differed significantly from each other in terms of total rainfall, peak intensity, and time to peak due to individual variations among the gauges.

3. Study Approach

Before the infiltration was performed, initial information on the study is obtained by selecting the testing point, land use data, topography data, and development plan data of the area. From the information data collection, some early indication of soil type of the area can be determined although sometimes data in the map are not the same on site. Overall, it is difficult and expensive to carry out infiltration test in the laboratory. Thus, in situ test, such as ring-infiltrimeter [3] and hand auger test will be carried out at the selected point for every study area.

Besides the field test, the soil sample of each point will be tested in the laboratory for sieve analysis and permeability test.

3.1 Field Works

Further exploration of the subsoil condition within the study area was made to provide additional data for further analysis. This includes upper soil sampling and infiltration tests. The field works test of the study area of Sungai Kedah consists of 70 points. Field exploration for upper soil sampling was carried out using hand auger (Fig. 3).

These boreholes were drilled by trained technicians according to instruction and specification given. Distributed soil samples extruded from split spoon sampler were sealed in air-tight plastic bags for visual examination. For infiltration test, double ring infiltrimeter ring instrument (Fig. 4) was used to determine the rate of infiltration of water into soil [4].



Fig. 3 Field test using hand auger.



Fig. 4 Field infiltration test using double ring infiltrometer.



The rate of infiltration is determined as the amount of water per surface area and time unit that penetrates the soil. This rate can be calculated on the basis of the measuring results and the Law of Darcy. The measurement exclusively takes place in the inner ring through which the water runs virtually vertically.

3.2 Laboratory

All the soil samples taken from the field test were brought to the laboratory [5] for further analysis. The particle size distribution for fine and course-grained soil test was carried out in accordance with the procedure of ASTM D422-63(2007)e2 [6]—Standard Test Method for Particle-Size Analysis of Soils. The

soil description follows the American soil classification system.

4. Infiltration Curve

4.1 Infiltration Analysis

The analysis of the infiltration test [7] result for Sungai Kedah catchment was summarized in Table 1.

The analysis was based on Horton Equation which was developed by Horton (1939) (Table 2). This equation was used to compare the measured equation parameters with published literature values. The equation is as follows:

$$f = f_c + (f_o - f_c)e^{-kt} \quad (1)$$

where, f = infiltration capacity ($\text{in}\cdot\text{h}^{-1}$); f_o = initial

Table 1 Soil type classification based on double ring observation.

Site No.	Location	Horton infiltration equation	f_c	f_o	k	Soil type
1	1a	$f = (10.3 + 259.7)e^{-0.79t}$	10.3	270.0	0.79	Sandy loam
	1b	$f = (7.5 + 127.5)e^{-0.83t}$	7.5	135.0	0.83	Sandy loam
2	2a	$f = (6.9 + 203.1)e^{-0.80t}$	6.9	210.0	0.80	Sandy loam
	2b	$f = (6.9 + 233.1)e^{-0.85t}$	6.9	240.0	0.85	Sandy loam
3	3a	$f = (4.0 + 56.0)e^{-0.66t}$	4.0	60.0	0.66	Sandy loam
	3b	$f = (4.0 + 41.0)e^{-0.82t}$	4.0	45.0	0.82	Sandy loam
4	4a	$f = (4.0 + 86.0)e^{-1.24t}$	4.0	90.0	1.24	Sandy loam
	4b	$f = (4.0 + 60.0)e^{-0.79t}$	4.0	60.0	0.79	Sandy loam
5	5a	$f = (6.0 + 144.0)e^{-0.80t}$	6.0	150.0	0.80	Sandy loam
	5b	$f = (7.7 + 92.3)e^{-0.72t}$	7.7	100.0	0.72	Sandy loam
6	6a	$f = (6.0 + 144.0)e^{-0.81t}$	6.0	150.0	0.81	Sandy loam
	6b	$f = (3.9 + 76.1)e^{-0.80t}$	3.9	80.0	0.80	Sandy loam
7	7a	$f = (4.0 + 86.0)e^{-0.71t}$	4.0	90.0	0.71	Silty loam
	7b	$f = (4.0 + 86.0)e^{-0.79t}$	4.0	90.0	0.79	Silty loam
8	8a	$f = (4.0 + 86.0)e^{-0.77t}$	4.0	90.0	0.77	clay loam
	8b	$f = (4.0 + 116.0)e^{-0.80t}$	4.0	120.0	0.80	clay loam
9	9a	$f = (4.0 + 86.0)e^{-0.75t}$	4.0	90.0	0.75	Sandy loam
	9b	$f = (4.0 + 116.0)e^{-0.80t}$	4.0	120.0	0.80	Sandy loam
10	10a	$f = (6.0 + 114.0)e^{-0.72t}$	6.0	120.0	0.72	Sandy loam
	10b	$f = (6.0 + 114.0)e^{-0.70t}$	6.0	120.0	0.70	Sandy loam
11	11a	$f = (4.0 + 116.0)e^{-0.80t}$	4.0	120.0	0.80	Silty loam
	11b	$f = (6.0 + 114.0)e^{-0.76t}$	6.0	120.0	0.76	Silty loam
12	12a	$f = (6.0 + 114.0)e^{-0.76t}$	12.0	120.0	0.76	Sandy loam
	12b	$f = (6.0 + 114.0)e^{-0.74t}$	8.0	120.0	0.74	Sandy loam
13	13a	$f = (4.0 + 116.0)e^{-0.80t}$	4.0	120.0	0.80	Silty loam
	13b	$f = (4.0 + 116.0)e^{-0.84t}$	4.0	120.0	0.84	Silty loam
14	14a	$f = (2.0 + 118.0)e^{-0.89t}$	2.0	120.0	0.89	Silty loam
	14b	$f = (6.0 + 144.0)e^{-0.78t}$	6.0	150.0	0.78	Silty loam
15	15a	$f = (4.0 + 120.0)e^{-0.80t}$	4.0	120.0	0.80	Silty loam
	15b	$f = (6.0 + 120.0)e^{-0.74t}$	6.0	120.0	0.74	Silty loam
16	16a	$f = (4.0 + 116.0)e^{-0.81t}$	4.0	120.0	0.81	Sandy loam
	16b	$f = (4.0 + 144.0)e^{-0.83t}$	4.0	150.0	0.83	Sandy loam
17	17a	$f = (4.0 + 86.0)e^{-0.67t}$	6.0	90.0	0.67	Silty loam
	17b	$f = (6.0 + 144.0)e^{-0.76t}$	6.0	150.0	0.76	Silty loam
18	18a	$f = (6.0 + 114.0)e^{-0.74t}$	6.0	120.0	0.74	Silty loam
	18b	$f = (4.0 + 116.0)e^{-0.82t}$	4.0	120.0	0.82	Silty loam
19	19a	$f = (6.0 + 114.0)e^{-0.70t}$	6.0	120.0	0.70	Silty loam
	19b	$f = (4.0 + 114.0)e^{-0.72t}$	6.0	120.0	0.72	Silty loam
20	20a	$f = (4.0 + 116.0)e^{-0.76t}$	4.0	120.0	0.76	Silty loam
	20b	$f = (2.0 + 118.0)e^{-0.89t}$	2.0	120.0	0.89	Silty loam
21	21a	$f = (6.0 + 114.0)e^{-0.76t}$	6.0	120.0	0.76	Silty loam
	21b	$f = (6.0 + 144.0)e^{-0.76t}$	6.0	150.0	0.76	Silty loam
22	22a	$f = (4.0 + 146.0)e^{-0.84t}$	4.0	150.0	0.84	Silty loam
	22b	$f = (6.0 + 144.0)e^{-0.73t}$	6.0	150.0	0.73	Silty loam

(Table 1 continued)

Site No.	Location	Horton infiltration equation	f_c	f_o	k	Soil type
23	23a	$f = (4.0 + 116.0)e^{-0.79t}$	4.0	120.0	0.79	Silty loam
	23b	$f = (6.0 + 114.0)e^{-0.76t}$	6.0	120.0	0.76	Silty loam
24	24a	$f = (6.0 + 144.0)e^{-0.80t}$	6.0	150.0	0.80	Silty loam
	24b	$f = (6.0 + 114.0)e^{-0.74t}$	6.0	120.0	0.74	Silty loam
25	25a	$f = (4.0 + 146.0)e^{-0.83t}$	4.0	150.0	0.83	Silty loam
	25b	$f = (4.0 + 146.0)e^{-0.84t}$	4.0	150.0	0.84	Silty loam
26	26a	$f = (4.0 + 146.0)e^{-0.83t}$	4.0	150.0	0.83	Sandy loam
	26b	$f = (4.0 + 146.0)e^{-0.84t}$	4.0	150.0	0.84	Sandy loam
27	27a	$f = (4.0 + 116.0)e^{-0.78t}$	4.0	120.0	0.78	Silty loam
	27b	$f = (4.0 + 116.0)e^{-0.81t}$	4.0	120.0	0.81	Silty loam
28	28a	$f = (4.0 + 116.0)e^{-0.81t}$	4.0	120.0	0.81	Sandy loam
	28b	$f = (4.0 + 146.0)e^{-0.84t}$	4.0	150.0	0.84	Sandy loam
29	29a	$f = (4.0 + 116.0)e^{-0.79t}$	4.0	120.0	0.79	Silty loam
	29b	$f = (4.0 + 116.0)e^{-0.80t}$	4.0	120.0	0.80	Silty loam
30	30a	$f = (2.0 + 58.0)e^{-0.74t}$	2.0	60.0	0.74	Silty loam
	30b	$f = (4.0 + 86.0)e^{-1.09t}$	4.0	90.0	1.09	Silty loam
31	31a	$f = (4.0 + 86.0)e^{-0.80t}$	4.0	90.0	0.80	Sandy loam
	31b	$f = (4.0 + 86.0)e^{-0.77t}$	4.0	90.0	0.77	Sandy loam
32	32a	$f = (4.0 + 86.0)e^{-0.80t}$	4.0	90.0	0.80	Sandy loam
	32b	$f = (4.0 + 56.0)e^{-0.67t}$	4.0	60.0	0.67	Sandy loam
33	33a	$f = (4.0 + 86.0)e^{-0.77t}$	4.0	90.0	0.77	Silty loam
	33b	$f = (4.0 + 86.0)e^{-0.80t}$	4.0	90.0	0.80	Silty loam
34	34a	$f = (4.0 + 86.0)e^{-0.80t}$	4.0	90.0	0.80	Sandy loam
	34b	$f = (4.0 + 86.0)e^{-0.79t}$	4.0	90.0	0.79	Sandy loam
35	35a	$f = (4.0 + 56.0)e^{-0.67t}$	4.0	60.0	0.67	Silty loam
	35b	$f = (4.0 + 86.0)e^{-0.76t}$	4.0	90.0	0.76	Silty loam

Table 2 Horton infiltration parameter values [8].

Soil type	f_c (mm·h ⁻¹) (in·h ⁻¹)	k (min ⁻¹)
Clay loam, silty clay loams	0-1.3 (0.05)	0.069
Sandy clay loam	1.3-3.8 (0.05-0.15)	0.069
Silt loam, loam	3.8-7.6 (0.15-0.30)	0.069
Sandy loams	7.6-11.4 (0.30-0.45)	0.069

infiltration capacity (in·h⁻¹); f_c = initial infiltration capacity (in·h⁻¹); k = empirical constant (h⁻¹); and t = duration of infiltration.

Eq. (1) assumes that the precipitation intensity is greater than the infiltration capacity at all time and that the infiltration rate decreases with time. From the measured data on the field, the infiltration curve of infiltration rate (mm·h⁻¹) versus time (h) was plotted in Fig. 5. From the graph plotted, the Horton Equation

can be determined for the study area which shows that the soil is mostly silty with clay that is suitable for paddy crops [9].

4.2 Infiltration Map

Based on the results of the infiltration test that were obtained, infiltration map was plotted for that area (Fig. 6). The map was plotted according to the permeability capacity of soil type for each area, which

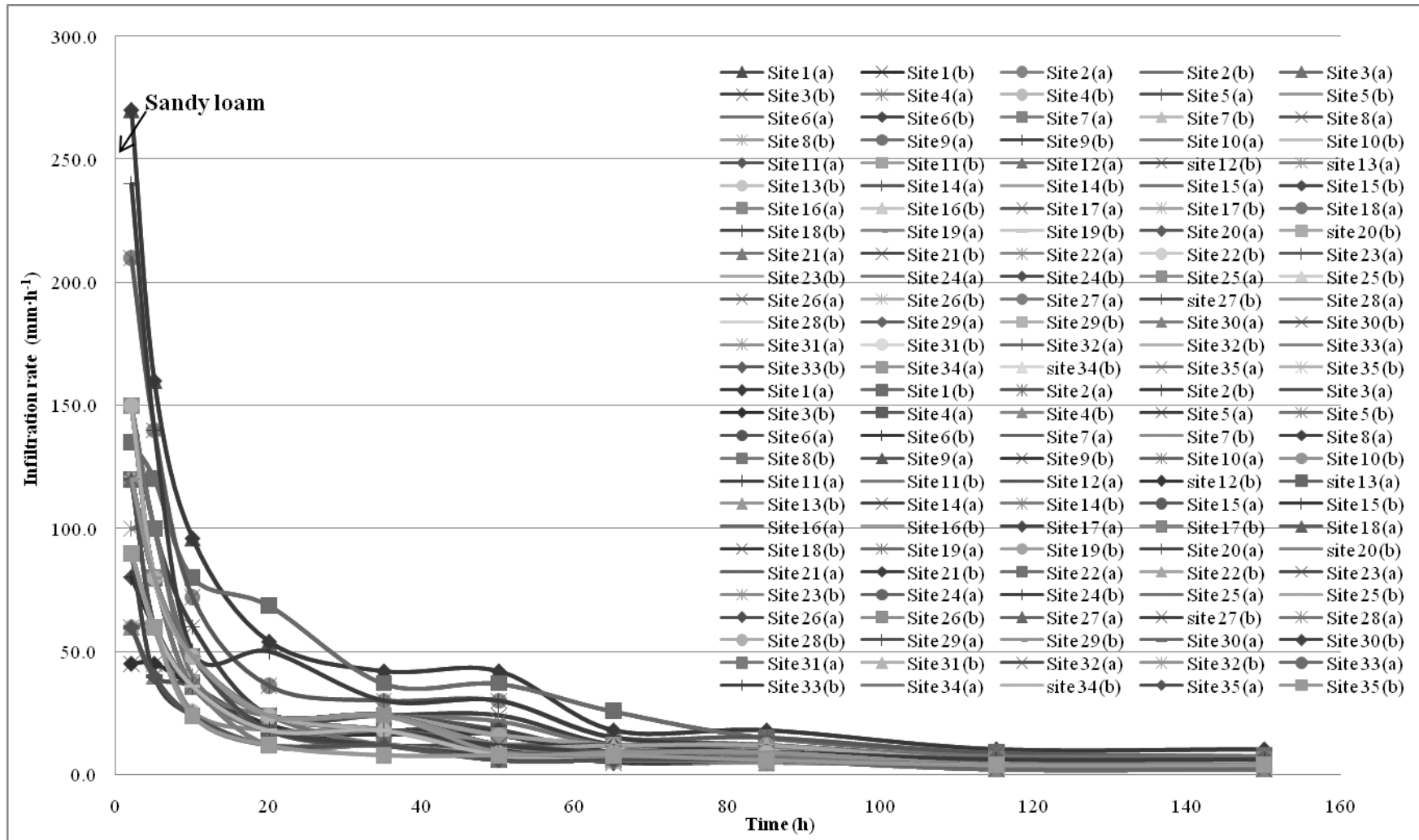


Fig. 5 Results of infiltration rate tests within 35 locations at Sungai Kedah catchment.

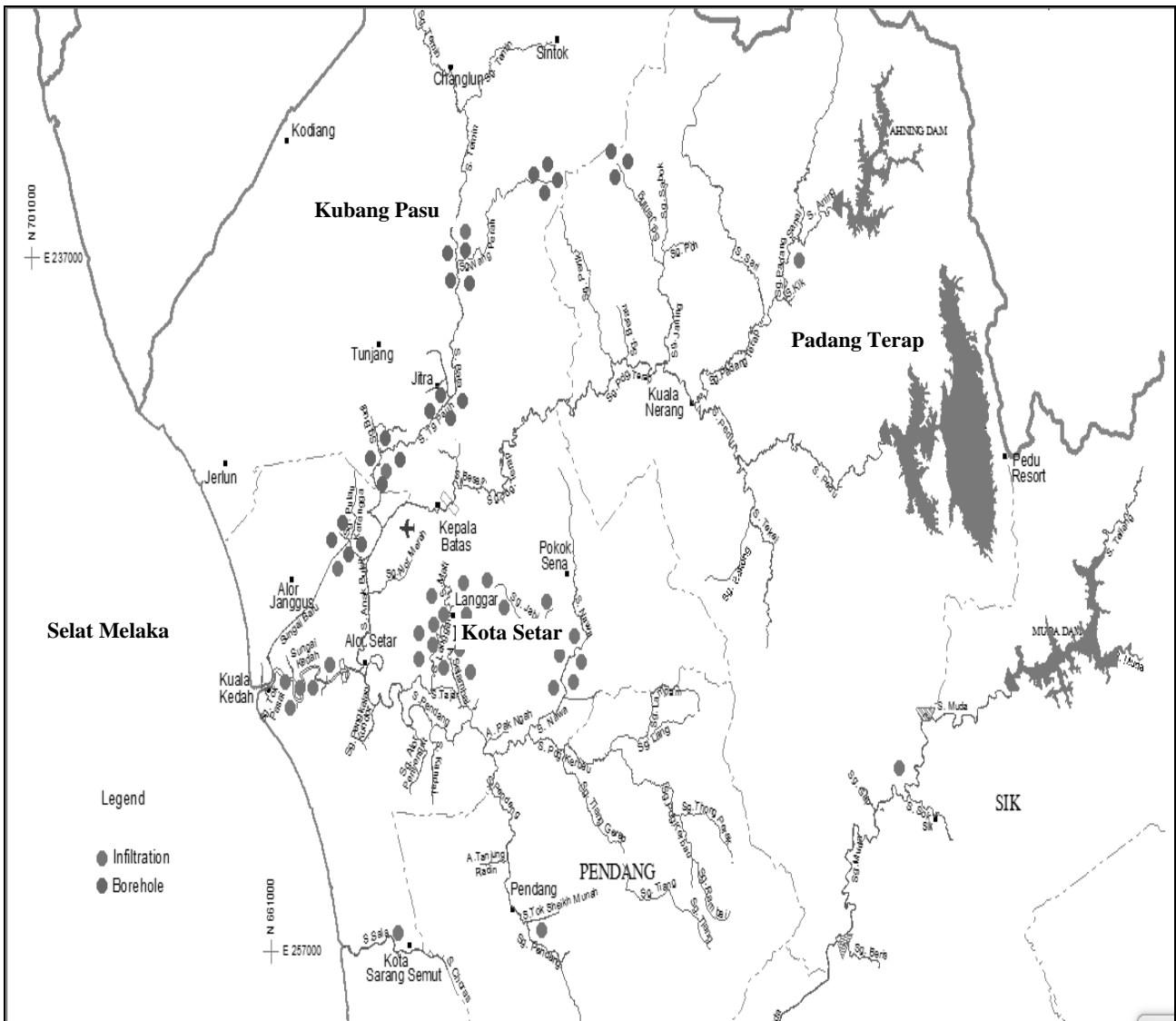


Fig. 6 Locations of 35 double-rings and 30 boreholes.

Table 3 Permeability indication ratio [10].

Ratio (f_o/f_c)	Permeability capacity
> 5	High permeability
3-5	Moderate permeability
< 3	Low permeability

is ranging from low permeability soil to high permeability soil [11]. The indication of low and high permeability is based on the f_o/f_c ratio as shown in Table 3.

5. Conclusions

Control at source approach in urban stormwater

management was still in early stage in Malaysia. To make this approach agreeable to all designers or engineers specifically, the soil infiltration and permeability capacity must be well known. By developing the infiltration map, designer could make a proper decision in applying control at source approach. In this study, the results show that the Sungai Kedah

has a low permeability soil type especially for the urban area. With this information, designer could make a right choice in designing urban stormwater drainage for future development for the rural area.

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