CHAPTER 1

SENSITIVITY OF CATCHMENT AREA DELINEATION ON PEAK RUNOFF ESTIMATION

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1.1 INTRODUCTION

Catchment delineation establishes the boundaries of a river basin or watershed, identifying the land area contributing to water flow into a specific river or stream. This process aids in determining geomorphological characteristics such as slope, flow direction, and stream networks [1]. It is widely used in hydrological modeling and predicting water quality parameters within a basin [1],[2].

Catchment delineation facilitates calculating the catchment area, crucial in hydrological analysis [1].

In water resource management, catchment delineation furnishes vital information about river basin hydrological characteristics, essential for understanding runoff dynamics, especially during peak runoff events. This analysis is significant in designing storm sewer systems, computing surface runoff, and determining peak discharge levels in rivers [3]. Additionally, catchment delineation helps understand the complex connection between water and sediment discharges during runoff events [4]. It offers insights into sediment origins, hydrological pathways, and factors governing concentration during event recession [5].

Using modeling tools and digital elevation models, catchment areas and their geomorphological characteristics can be identified [6]. This information is critical for understanding water flow patterns and catchment response to precipitation [1]. The complexity of catchment delineation, influenced by topographical features, land use, aridity, slope, distance to the coast, and hydrological processes [7], affects runoff predictions' reliability.

With climate change and human activities modifying landscapes, precise catchment delineation methods are crucial due to their significant impact on runoff variation [8]. Inaccurate delineation can lead to substantial errors in catchment boundaries, affecting hydrological calculations [9]. Understanding the sensitivity of catchment delineation methods is vital for resilient water resource management. This study addresses the gaps in understanding catchment delineation sensitivity, particularly regarding peak runoff, aiming to refine methods and enhance peak runoff event management.

1.2 EFFECT OF CATCHMENT AREA ON PEAK RUNOFF

The size and characteristics of a catchment area directly influence the volume of water that collects and flows toward the outlet point. [10] noted that geomorphological analyses reveal that catchment characteristics such as area, relief, and drainage patterns significantly influence hydrological responses. Larger catchments typically experience delayed peak hydrographs due to longer lag times and time of concentration, affecting flow behavior.

[11] highlighted that catchment area is crucial in explaining inter-catchment variability in peak discharge and runoff coefficients. Larger catchments exhibit different runoff behaviors compared to smaller ones; for small storms, factors like catchment storage, connectivity, and antecedent conditions control peak discharge, whereas, for larger storms, surface flow attenuation is more dominant. [12] emphasized that catchment size is a key morphometric feature influencing river hydrological responses, leading to variations in peak flow characteristics even within similar geological settings. Furthermore, [13] pointed out that catchment shape and other morphometric characteristics can impact peak flows, with shorter response times and higher peak flows observed in catchments with specific geometrical attributes.

1.3 STUDY AREA AND DATA COLLECTION

The study on rainfall-runoff specifically examines the catchment of Taman Madu, Yong Peng in Johor. Taman Madu is located in Yong Peng town of Batu Pahat district. The chosen rainfall station near Taman Madu is Empangan Sembrong (Sembrong Dam) (Figure 1.1).

(a) (b)

Figure 1.1: Study area (a) Yong Peng town; (b) Empangan Sembrong station

This station was selected based on the Urban Stormwater Management Manual of Malaysia [14]. Total catchment area delineated ranges between 40 ha and 50 ha.

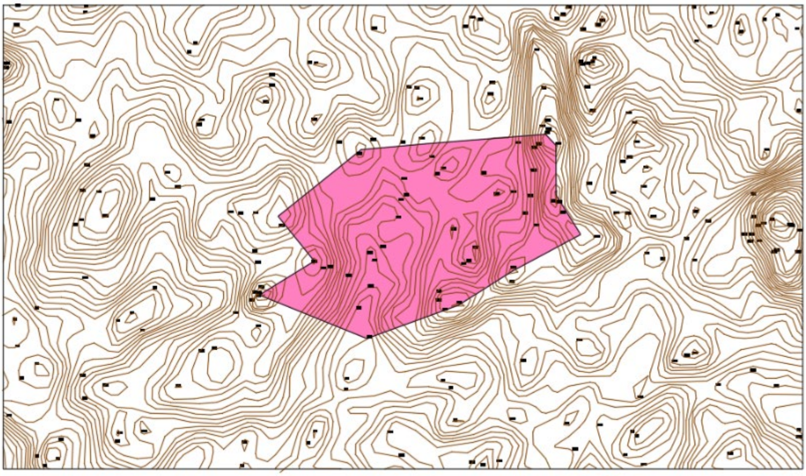

Figure 1.2: Catchment boundary of study area is delineated based on contour level

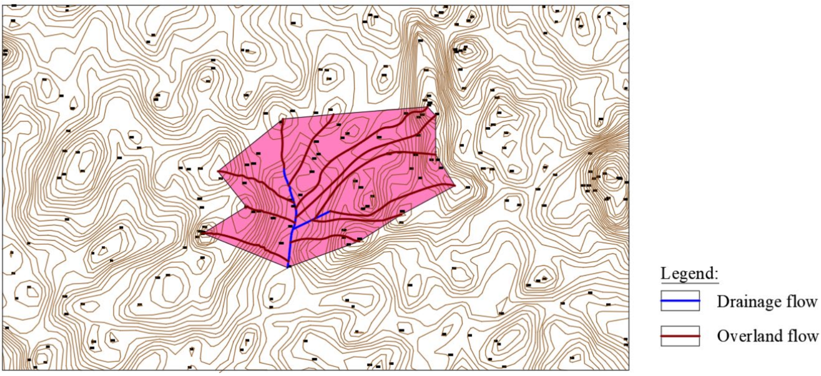

Figure 1.3: Drainage flow and overland flow paths of Taman Madu

Meanwhile, elevation and topography data are acquired using Global Mapper, a Geographic Information System (GIS) software. The SRTM Worldwide elevation data is imported into the software, which helps in the creation of contour maps using Global Mapper's tools. The contour map that is created is used to delineate the catchment boundary (Figure 1.2) and to determine the drainage pathways (Figure 1.3).

1.4 METHODS

The Rational method is a straightforward empirical approach used to estimate peak runoff rates in drainage areas, albeit with some limitations. The developed area (residential houses) and undeveloped area were estimated using AutoCAD software. Runoff coefficient C = 0.90 was selected from MSMA [14] for residential houses (link and terrace houses). Overland path and drain path for the catchment and the drainage characteristics were determined to estimate the time of concentration. Intensity of rainfall i (mm/hr) for study area is determined using Eq. (1.1).

$$i = \frac{\lambda \, T^{\kappa}}{(d + \Theta)^{\eta}} \tag{1.1}$$

where, T = average recurrence interval (year) of rainfall event, d = duration of rainfall = time of concentration t_c (hour), and λ, κ, θ, η = fitting constant for intensity-duration-frequency empirical equation [14]. Fitting constants used are λ = 60.568, κ = 0.163, θ =0.159, and η = 0.821 of Empangan Sembrong station

The peak runoff Q_p is estimated using Eq. (1.2).

$$Q_p = \frac{CiA}{360} \tag{1.2}$$

where, A = area of catchment (ha).

The HEC-HMS model, developed by the Hydrological Engineering Center of the U.S. Army Engineering Corps, is an advanced Hydrological Model System that combines HEC-1 with GIS [15]. Using Terrain Data manager and Basin Model Manager, terrain map of Taman Madu and a basin were created. In this study, SCS curve number and SCS unit hydrograph are used. The curve number is obtained through the QGIS software by obtaining both global curve number data and shape file of the catchment area (Figure 1.4).

The SCS unit hydrograph is a mathematical model used to convert excess rainfall into a runoff hydrograph. The lag time tL in SCS unit hydrograph is calculated using Eq. (1.3) and Eq. (1.4).

$$t_c = \frac{L^{0.8}(S+1)^{0.7}}{1140Y^{0.5}} \tag{1.3}$$

$$t_L = 0.6t_c \tag{1.4}$$

where, t_L = lag time (hr), t_c = time of concentration (hr), L = length of flow (ft), Y = average watershed land slope (%), and S = maximum potential retention (in). Meteorological model, control specifications, and time series data were created to simulate the runoff processes.

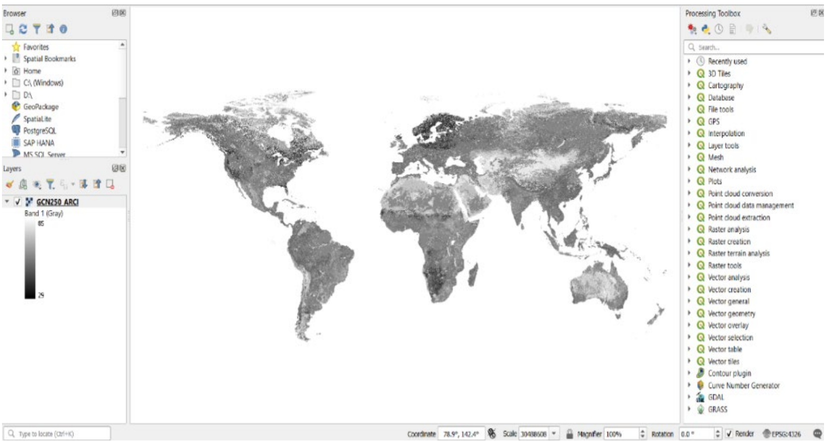

Figure 1.4: Global data for curve number

1.5 TIME OF CONCENTRATION

Through zonal statistics in QGIS software, CN for the catchment was determined to be 80. This value indicates that the area has a moderate level of runoff potential, which is influenced by factors such as soil type, land use, and treatment. Since Taman Madu is in urban areas, with impervious surfaces like roads and buildings, it tends to have higher CN values due to reduced infiltration.

The lag time for three different catchment areas of 45 ha, 50 ha, and 40 ha was calculated and found to be the same across all areas (Table 1.1). This calculation involved determining the travel time of water from the most distant point in the catchment to the outlet point.

Table 1.1: Lag time calculations

L (km)	L (ft)	S	Y (m/m)	Y (%)	t_c (hr)	t_L (hr)	t_L (min)
1.131	3711.516	2.5	0.051	5.073	0.671	0.403	24.169

The catchment with 3 different estimated areas shared similar topographical features and slopes, the consistency in lag time is acceptable. This has shown that lag time is not solely dependent on the catchment area but rather on the hydraulic properties and topographical characteristics of the watershed.

Table 1.2: Lag time calculations

Catchment area (ha)	t_c (min)
50	12.46
45	12.46
40	12.33

Time of concentration t_c is the time taken for water to travel from the most distant point in the catchment to the outlet. Highest t_c was chosen for each catchment to ensure the peak runoff calculation considers the entire watershed. Table 1.2 shows that the area of catchment A also has influence on time of concentration t_c.

1.6 SIMULATED RUNOFF

A comparison between simulated runoff with calculated runoff was conducted for three different catchment areas, i.e. 50 ha, 45 ha, and 40 ha (Table 1.3, Table 1.4, and Table 1.5).

Table 1.3: Lag time calculations

Catchment area (ha)	ARI (year)	Duration (min)	Peak flow Q_p (m^3/s)		Difference (%)
			$Q_{calculated}$	$Q_{simulated}$	
50	20	12.46	28.116	24.5	12.9
		30	17.375	13.3	23.5
		60	10.930	7.1	35.0
	50	12.46	32.645	29.4	9.9
		30	20.173	16.2	19.7
		60	12.690	8.7	31.4
	100	12.46	36.549	33.6	8.1
		30	22.586	18.7	17.2
		60	14.208	10.2	28.2

Table 1.4: Simulated runoff and designed runoff for catchment area (45 ha)

Catchment area (ha)	ARI (year)	Duration (min)	Peak flow Q_p (m^3/s)		Difference (%)
			$Q_{calculated}$	$Q_{simulated}$	
45	20	12.46	25.305	22.1	12.7
		30	15.637	12	23.3
		60	9.837	6.4	34.9
	50	12.46	29.381	26.4	10.1
		30	18.156	14.6	19. 6
		60	11.421	7.9	30.8
	100	12.46	32.896	30.2	8.2
		30	20.328	16.8	17.4
		60	12.787	9.2	28.1

The difference in Q_p between $Q_{calculated}$ and $Q_{simulated}$ is consistent for all three catchment areas. Difference between calculated and simulated Q_p found for area of 50 ha, 45 ha, and 40 ha are in the range of 8.1%-35%, 8.2%-34.9%, and 8.1%-34.8%, respectively.

Table 1.5: Simulated runoff and designed runoff for catchment area (40 ha)

Catchment area (ha)	ARI (year)	Duration (min)	Peak flow Q_p (m^3/s) $Q_{calculated}$	$Q_{simulated}$	Difference (%)
40	20	12.33	22.602	19.7	12.8
		30	13.900	10.7	23.0
		60	8.744	5.7	34.8
	50	12.33	26.243	23.6	10.1
		30	16.139	13	19.4
		60	10.152	7	31.1
	100	12.33	29.382	27	8.1
		30	18.069	15	17.0
		60	11.367	8.2	27.9

Based on the calculated Q_p, sensitivity of Taman Madu catchment area on peak flow has been evaluated. Figure 1.5, which is a semi-logarithmic graph shows calculated Q_p of three event durations of d = 12.46 or 12.33 min, 30 min, and 60 min for three return periods, i.e. (a) T = 20-year, (b) T = 50-year, and (c) T = 100-year.

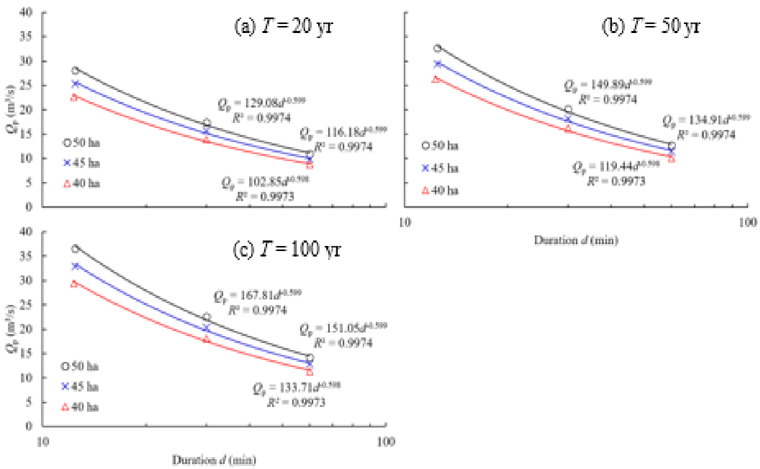

Figure 1.5: Area of catchment A has influence on peak discharge Q_p in all three return periods (a) T = 20-yr, (b) T = 50-yr, and (c) T = 100-yr

With coefficient of determination $R^2 \geq 0.9973$, it has been shown that Q_p increases with increase in A, shorter rainfall duration d, and higher return period T. Considering the rate of increase presented in the equations, the coefficient of change C_c is plotted against the area of catchment (Figure 1.6). It has been shown that the rate of increase of Q_p which is C_c is about 3-fold for rainfall event of 50-year ARI, 3.41 times for rainfall event of 100-year ARI, and 2.62 times for rainfall event of 20-year ARI, for any variation of catchment area.

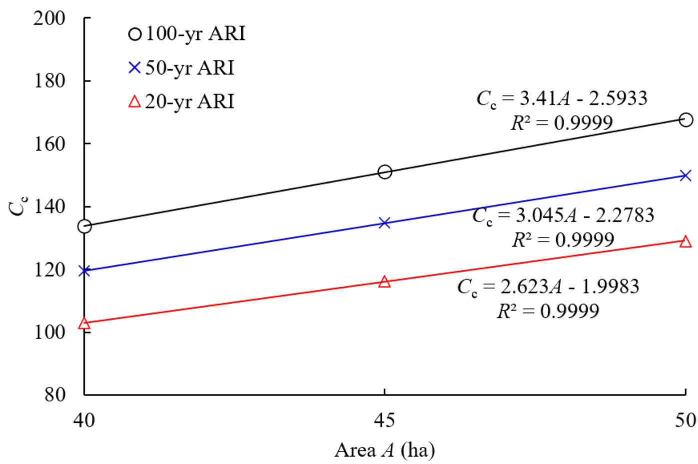

Figure 1.6: Effect of catchment area is greater for higher return period, which is shown by greater C_c value

1.7 CONCLUSION

In summary, the CN of 80 indicates that Taman Madu in Yong Peng has a moderate runoff potential. Significant differences were observed between the runoff simulated using HEC-HMS and the runoff calculated via the Rational method. The Rational method, often used for designed runoff calculations, simplifies complex hydrological processes by assuming uniform rainfall intensity and a constant runoff coefficient, which may not be accurate in real life.

Variation in catchment area significantly impact the peak runoff. The table of tolerance for peak runoff in different catchment areas shows significant differences between simulated and designed runoff. Due to limited scope of the study, it is recommended that future studies should incorporate higher resolution data and more diverse rainfall events to refine the accuracy of runoff predictions.

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