Jurnal
Teknologi

Full Paper

SIMULATION OF FLOOD RISK AREA IN KELANTAN WATERSHED, MALAYSIA USING NUMERICAL MODEL

Article history
Received
15 July 2015
Received in revised form
2 August 2015
Accepted
26 August 2015

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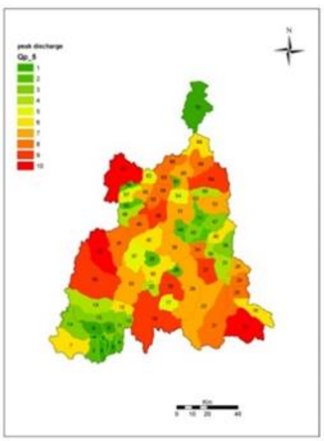
Graphical abstract



Abstract

Flood events have recently increased and caused extensive damages to the agricultural area and infrastructures, despite enormous efforts to decrease this hazard. Modeling of runoff can be a suitable approach to determine the effective factors in flooding, and to explore reasonable solution and thus to be able reduce hazard on watersheds. The current work attempted to derive basin and sub-basins, stream network, aspect, slop and all relevant physiographic parameters of Kelantan watershed in order to estimate depth of runoff using DEM data , satellite images and field study. In addition, the maximum rainfall intensity of all the meteorological stations were extracted and the interpolation of the values obtained, led to derive a contour map as rainfall intensity for the watershed. Soil Conservation Service (SCS) model was employed to calculate the surface flows, and to derive the flood hydrograph for all the sub-basins at the return periods of 5,10,25,50,100, considering to the Curve Number (CN) is a function of land use, soil, and primary moisture content. HEC-HMs model was calibrated for the study area using observed storm rainfall and recorded floods at the number of hydrometric stations. A good agreement was obtained between simulated and observed data with a correlation of 82%. Calibrated model was used to simulate depth of runoff in different return period that led to derive flood risk maps for Kelantan watershed. Results obtained revealed that flooding could be moderated and managed within a number of the sub - basins through implementing a technical scheme, depending on characteristic of the sub- basin, and its effect on the flood peak.

Keyword: Runoff, ArcGIS, HEC-HMS, flood management, hydrology, watershed management

1.0 INTRODUCTION

Flooding is a serious concern that threat many areas of the world [1, 2]. The flow of a large volume of runoff into streams and rivers may lead to emerge flood, and cause damage to structure or cropland. Occurrence of flood in Kelantan watershed seems to be a serious problem in the monsoon season (November to January). According to past studies, the estimate flood volume under the 50-year flood condition at Kusial Bridge has been about 6 billion m3 [3]. Severe flooding occurred in 1926 and 1967. In the 1967 floods, 84% of the Kelantan population (537,000 people) was badly affected. Some 125,000 people were evacuated and 38 drowned. The peak discharge of a flood is influenced by many factors including the intensity and duration of storms, the topography, and geology of stream basins, vegetation, and the hydrologic conditions preceding storm land use. In undeveloped areas such as forests and grasslands, rainfall water is stored on vegetation, in the soil column, or in surface depressions. When this storage capacity is filled, runoff flows slowly through soil as subsurface flow. In contrast, urban areas, where roads and buildings cover much of the land surface, have less capacity to store.

Various methods can be used to control flood in water resources schemes like predictive, heuristic, and optimum checkers [4, 5, 6, and 7]. Used estimators in flood performance with a kalman filter had a minimum act in adjusting flood [8]. Various models were developed that could contribute to study the runoff and flood in catchments [9,10] . Rainfall- runoff is a significant element in modeling process [11]. Kabir [12] exprienced that in the excess rainfall was a value of 55.9 in a selected percipatation on a pasture land. Adjustments between analytical skill, performance time, and set-up time are recognized that the best technique for a particular use will depend on obtainable statistics,calculating resources, time limitations, and the specific modeling objectives [13]. HEC-HMS model can convert the precipitation excess to overland flow and channel runoff, as well as a hydraulic model of HEC-RAS enable to replicas unstable state flow through the river channel network based on derived hydrographs by the HEC-HMS system [14].

The main objective of this work is to identify environmental and ecological impacts of watershed development that may affect the flood and stream flow patterns and to determine flood risk area during the flooding season.

2.0 MATERIAL AND METHOD

2.1 Study Area

Kelantan watershed that covers a catchment of about1 2981 km^2, was selected as study area. This area is expanded in the north eastern part of peninsular between latitude 5°.30" to 6°.30'' N and in eastern longitude from 101°.25''to 102°.45'' E. Highest and lowest altitude of the watershed was estimated 2135 and 10 m above sea level, where are located in south and north of the area respectively. The mean annual rainfall of the watershed was estimated over 2510 mm. Two types of monsoon that effect the climate of the area, are the southwest and northeast monsoon, and occur in the months of May to August and November to February. First and second monsoon period occur in the months of March to April and September to October respectively. Average annual discharge of Sg Kelantan River basin estimated about 557 m3/s at Guillemard Bridge, and vegetation cover is mainly formed from virgin jungle, rubber, tobacco, paddy, oil palm, other agricultural schemes, and urban area. Shale, mudstone, and limestone are main geological formations of Kelantan watershed. The area is covered by deep soil with depth of more than 15 m in localized parts. A fine sandy loam texture is observed in large area of the watershed. Figure 1 indicates location and geographic coordinate of Kelantan watershed.

Figure 1 Geographic location of Sg. Kelantan river basin

2.2 Data Collection

2.2.1 Daily Rainfall

Daily rainfall of over 50 meteorological stations were collected for at least past -30 years from 1985 to 2014 to analyze to use in relevant model. The data were obtained from Ministry of Natural Resources, Malaysia with cooperation of University Putra Malaysia. In first step, quality of the data obtained was investigated to select an acceptable statistical period with longest corresponding period. The missing values in the data series for the period of 1992 – 2014 were estimated using the weighting method such as the inverse distance, the normal ratio, and the correlation between the target and the neighboring stations.

Given to missing date in some stations, finally a 22-year statistical period was considered from 1992 to 2014 to analyze and then employ in this study. Maximum daily rainfall data for raining months of each year were extracted for the meteorological stations as initial data to estimate maximum daily rainfall in return period of 5,10,20,50 and 100 years. Gumbel statistical distribution was used to compute maximum precipitation in considered return periods.

The probably models are developed to provide a statistical distribution of the observation for the various purpose such as for data generation and modeling climatic events that can be used to describe the physical explanation of the rainfall occurrence. In this study, statistical Gumbel distribution was used to generate maximum daily rainfall in return period of 5, 10, 20, 50, and 100 years.

Figure 2 demonstrates spatial distribution stations in Kelantan and Thiessen polygons used to compute mean maximum rainfall using Arc map software.

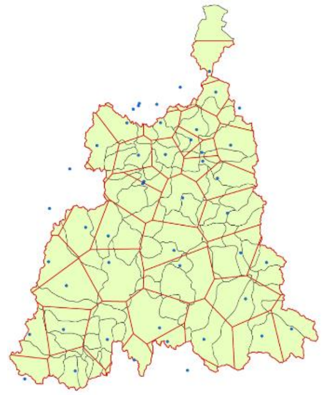


Figure 2 Spatial distribution of rainfall station and Thiessen polygons combined with sub–basins

2.2.2 CN Map

Curve number (CN) is an important factor to generate the runoff that its values range from zero to 100. Several factor like land cover, land use, hydrological soil group were used to estimate CN amount in all of the cells in watershed using ArcGIS and satellite image. The weighted averages of CN were calculated for all the sub catchments to estimate depth of surface flow using below equation. CN values for all the sub catchment are presented in Table 1.

$$\text{CN} = \sum_{x=1}^{N} \text{CNx} * \text{Px} \quad (1)$$

Where CN is curve number, P is percent of area and x is number of district with different CN

2.2.3 Sub Catchment

The watershed was divided to several sub catchment based on topography and geographical situation of river. Physical characteristic of all the sub catchment were calculated to determine depth of runoff using relevant extensions of ArcGIS software. An effectiveness of the sub basin in emerging huge flood were investigated through comparing the calculated parameters of the basin. The following equation were used to estimate the effective parameters.

$$T_L = \frac{L^{0.8}(S+1)^{0.7}}{1900Y^{0.5}} \quad (2)$$

$$Tc = \frac{5}{3} * T_L = 0.6T_c = L^{0.8} * \frac{(S+1)^{0.7}}{1900Y^{0.5}} \quad (3)$$

$$T_p = \frac{T_R}{2} + T_L T_R = 0.133T_c \quad (4)$$

$$Q = \frac{1}{2} * q_p * (T_p + T_r) \quad (5)$$

$$q_p = \frac{2.08AQ_{(si)}}{T_p} \quad (6)$$

$$C_c = 0.28 * \frac{p}{\sqrt{A}} \quad (7)$$

Where L is Hydraulic length (ft), S is retention (in), T_L lag time(hr), Tc is Concentration time (hr), Y is height (In), T_P is peak time (hr), A is area (km^2), form coefficient(Cc), p is perimeter (km), q_p is Maximum discharge (m^3/s)

2.3 Model Description

Surface runoff can be simulated using Hydrologic Engineering Center-Hydrological Modeling System (HEC-HMS), version 3.1. The model has developed by the US army to investigate and model the runoff of watershed. HEC-HMS [15] has capability to choose one of the numerous infiltration loss parameterizations.

2.4 Model Calibration

Calibration of the model through appropriate data is an essential stage in the making of a reliable basin demonstration. Watershed parameters such as infiltration coefficients, time of concentration, vegetation cover, and base flow may need to adjust to represent a best fit between computed and measured values. Discharge output from a rainfall–runoff model is generally calibrated with observed stream flow.

2.5 SCS Method

SCS model that is developed by soil conservation service of USA in 1969 was used to estimate depth of runoff based on storm rainfall depth in different return periods.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (8)$$

$$S = \frac{1000}{CN} - 10 \quad (9)$$

Where Q is depth of runoff for the watershed (mm), P is maximum average daily rainfall (mm), S is the potential maximum retention and CN is a runoff curve number that is function of land use, soil moisture and other factors affecting runoff and retention in a water shed.

3.0 RESULTS AND DISCUSSION

3.1 Potential Retention

Figure 3 demonstrates CN map of Kelantan watershed, Malaysia. With respect to SCS instruction, combining of the vegetation cover, land use and soil hydrologic group maps resulted in deriving the CN map for the Kelantan basin. According to the map, over 35 percent of the watershed is increased to a CN of 80, indicating a high potential of basin to produce runoff during rainfall event occurrences. Increase of CN lead to reduce rate of retention, and storage capacity of land. Reason of this reaction refer to type of land cover and changes in land use.

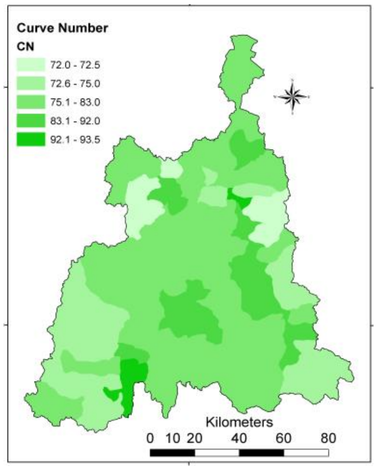


Figure 3 CN map of Kelantan watershed

3.2 Sub–catchments

Kelantan watershed was divided to several sub-catchments based on topography and existing stream network using DTM data and ArcGIS software to identify and separate flood risk area in the watershed. Physiographic characteristic of all sub catchment were estimated including, area, perimeter, concentration time, highest and lowest height of basins and compactness coefficient. Figure 4 indicates spatial distribution of sub basin in Kelantan River, derived using Arc map. The watershed divided to 73 sub basins that surface area varies in the range of 25 to 670 km^2. Hydrologic and physiographic properties of the entire sub basin are given in Table 1.

(a)

(b)

Figure 4 The physiographic map (a) and stream network of Kelantan watershed (b)

Table1 Hydrologic and physiographic properties of the entire sub basin

basin	L(km)	Slop%	CN	A (km^2)	basin	L(km)	Slop%	CN	A (km^2)
1	16.3	2.9	75.0	59.0	38	15.5	1.8	91.0	108.6
2	11.4	8.0	75.0	25.9	40	47.2	3.0	75.0	670.1
3	17.8	4.5	75.0	106.6	41	23.6	6.3	82.5	195.1
5	17.5	5.0	75.0	46.9	43	29.2	2.9	75.0	136.7
8	15.5	1.7	93.5	51.6	44	34.4	2.7	82.0	349.4
9	28.6	4.7	79.0	306.4	45	31.2	4.4	82.5	271.9
10	14.5	2.2	75.0	53.8	46	24.7	6.2	81.0	206.9
11	20.8	0.4	75.0	107.6	47	16.7	1.2	80.0	85.0
12	9.1	1.2	93.0	48.1	48	19.8	1.0	81.0	96.1
14	29.9	1.7	75.0	401.9	49	20.8	4.0	82.5	132.1
15	31.7	5.0	81.0	190.4	50	21.6	7.2	82.5	171.1
16	30.9	3.6	75.0	217.9	51	23.8	4.0	72.5	133.1
19	36.5	0.7	75.0	192.7	52	23.4	6.3	72.0	124.2
20	15.6	7.5	82.0	119.2	55	19.1	8.7	72.0	69.3
21	50.3	1.6	82.5	684.7	57	28.0	3.1	72.5	222.2
22	36.2	3.9	75.0	287.0	59	24.7	1.3	75.0	107.4
24	59.5	0.9	83.0	473.6	60	14.8	1.5	92.0	82.4
25	15.7	5.2	91.0	82.7	61	24.6	2.9	74.5	102.3
26	67.4	3.1	82.5	454.8	62	18.6	8.9	72.0	97.3
28	15.2	3.6	79.0	98.8	63	17.8	1.4	81.0	92.2
29	18.8	0.3	91.6	216.1	64	17.6	6.1	72.5	49.9
30	9.3	0.0	79.0	50.8	67	14.6	1.4	72.5	77.9
31	21.1	0.5	91.6	186.5	68	19.0	2.9	81.0	109.1
32	19.9	3.1	75.0	111.3	69	34.6	2.5	82.0	314.4
33	51.2	2.2	82.0	480.3	71	19.4	2.9	83.0	117.2
35	17.4	5.7	75.0	81.3	72	51.5	2.1	81.0	439.1
37	15.0	7.8	81.0	87.3	73	25.3	1.1	91.0	177.2

L=length, CN=Curve Number, A=Area, S= slope

3.3 Maximum Daily Rainfall

Mean maximum daily rainfall was computed for the entire sub basin in return period of 5,10,20,50,100 years using Thiessen polygon method and spatial distribution. SMADA software was also employed to investigate statistical frequency analyses. Table 2 shows result of estimation of maximum precipitation for each the sub-basin. According to the Table 2, mean Maximum rainfall of the sub-basins vary in a range between 33.6 to 262.9 mm in return period (Rp) of 5,10,20,50,100 years. Figure 5 indicates the combined map of Thiessen polygon map with sub-basin to extract mean rainfall for center of the catchment.

Table 2 A summary of climatologic information estimated for all the sub catchment

Amount	Maximum daily Rainfall (mm)				
	Rp_5	Rp_10	Rp_20	Rp_50	Rp_100
Min	4.7	6.4	37.6	50.1	60.5
Max	71	194.3	310.3	424.5	567.7
Mean	33.6	69.6	166.8	214.4	262.9

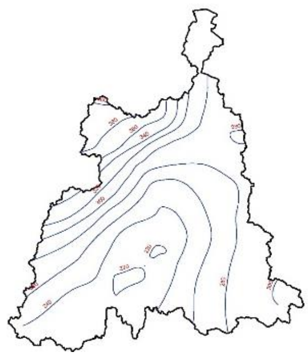


Figure 5 Max. Daily Isohyet map with 50 years return period (Rp)

3.4 Peak Discharge

Peak discharge of specified hydrometric stations were investigated to derive flood hydrograph according to measured data in the intended station corresponding to maximum rainfall occurred in watershed. Given to the events that model used in this study was calibrated to the watershed for computing maximum discharge in each sub watershed. Table 3 demonstrates peak discharge corresponding maximum rainfall events.

Table 3 Peak discharge of hydrometric observation station Kelantan watershed, Malaysia

Stations No.	5222452	5721442
Station Name	Kg Tualang	Guillemard Bridge
Catchment Area (km^2)	2430	11900
Mean annul discharge (m^3/s)	109.8	557.5
Maximum discharge (m^3/s)	4020	12900
Mean maximum discharge m^3/s	1636	5387
Minimum discharge (m^3/s)	32.4	153

3.5 Compactness Coefficient

Compactness coefficient (Cc) of a basin reflects the geometric shape of a catchment that effect on rate discharge. It is a function of perimeter and area of watershed and defines as the ratio of perimeter of a basin to circumference of circular area that equals the area of the watershed (Eq 10). The following formula was used to estimate Gravelius coefficient of entire the sub - basin in order to compare amount of its effects in emerging huge flood. Results of computation are presented in Table 4. According to the table, the coefficient is categorized in 8 classes based on result obtained. Result indicated that close to 24 percent of sub catchments have nearly a circle shape, and therefore could have high positional to generate a huge flood. Because of such physiographic property, runoff from all aspect of catchment would travel to outlet at the same time as a result produce a peak flood. In flood management projects, necessarily, part of measures should be focused on the sub-basin with low compactness rather than high coefficients.

$$C_c = \frac{0.28P}{A^{0.5}} \quad (10)$$

Table 4 Results from computation of compactness coefficient

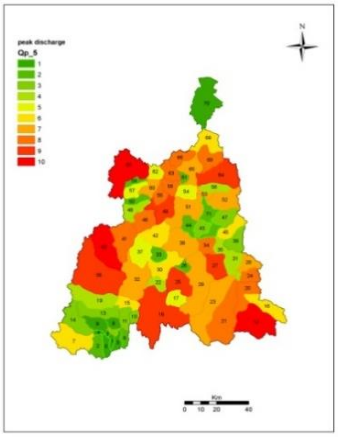
Class Cc	percent	
<1.1	5.6	1
1.1-1.2	18.3	2
1.2-1.3	25.3	3
1.3-1.4	19.7	4
1.4-1.5	12.6	5
1.5-1.6	8.4	6
1.6-1.7	8.4	7
1.7-2.1	1.4	8
min		1.1
max		2.1
mean		1.4

3.6 Model Calibration and Validation

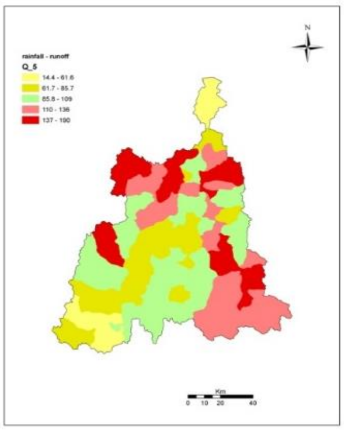
Calibration of hydrological model led to obtain an acceptable agreement between simulated and observed values of flow, so that timing of peak flow and hydrograph profile reasonably harmonized. The profile of flood hydrograph in the most sub catchment were accurately fitted with measured profile, indicating the model was able to reproduce observed values for the sub basin. However, in beginning of calibration process, model needed to adjust values of curve number(CN), and also concentration time on a regional scale of watershed to improve required parameters for majority of sub basin in order to reproduce runoff accurately. For example, while preliminary estimation of sub catchment indicated a bias of 201, a mean absolute error of 113% and a correlation coefficient of 0.85, after calibration of model the parameters improved to values of 14, 17, and 0.91 respectively. The model was tested to validate on next 5 years reproducing the newly measured data in an acceptable competition with a correlation coefficient of 0. 87.

3.7 Application of Calibrated Model

Calibrated model (HEC-HMS) was employed to estimated depth of runoff and discharge in outlet for all sub basins and entire watershed using the SCS package included in the model. Physical parameters of all sub basins were allocated the model to compute the effectiveness of each sub basin (Independently) in peak discharge of watershed in outlet or intended point of basin. Simulation of runoff in different return period, led to derive runoff and maximum discharge maps, indicating flood risk area. Figures 6-a and 6-b demonstrated as example of results obtained from simulation of depth of runoff and peak discharge in the watershed for 5- years return period.



(a)

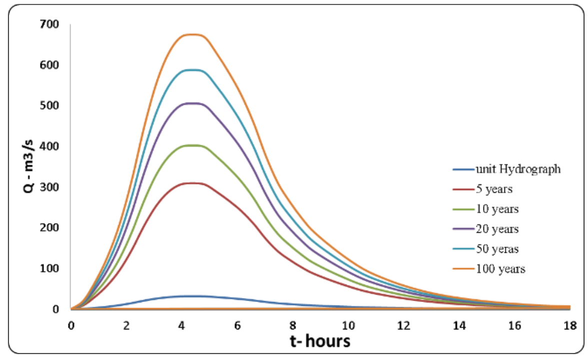


(b)

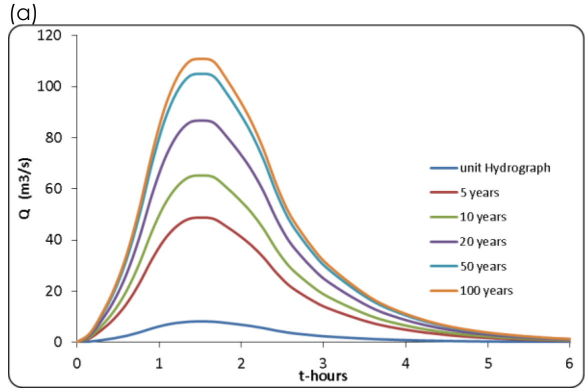
Figure 6 Depth of runoff map (a) and Maximum discharge in 5-years return period (b)

A summary of maximum discharge obtained for all sub-basin are given in Table 5. Figures 7-a and b indicate unit and flood hydrograph of number 1 and 40 sub – catchment of Kelantan watershed due to rainfall event occurrence in a 5- years return period. Sub- basin number 40 could emerge a peak discharge of 650 m^3/s during 100- years return period while sub basin one can create a peak discharge of 110 m^3/s at the same return period.

Given to the peak discharge occurrence in sub-basin (Table 5) and its effect on main river discharge in Kelantan watershed, it is necessary to manage the huge flood, and decrease peak discharge through constructing variety of mechanical structures like storage dam and pond, considering the characteristic of watershed. A number of the sub-catchments have same concentration time in connection to the main river, hence such property of basin can lead to significant increase peak discharge at the main river. For this purpose, some technical measures could contribute to increase the traveling time in sub basin while another sub-catchment enable to evacuate its surface flow without damage to riverbank or any infrastructures placed around Main River.



(a)



(b)

Figure 7 Unit and flood hydrograph of 5,10,20,50 and 50 years for sub basin 40 (a) and 1(b)

Table 5 Maximum discharge of all sub catchment Malaysia for return period 5 years

basin	TC	TL(hr)	Tp	qp(m^3/s)	basin	TC	TL(hr)	Tp	qp(m^3/s)
1	2.3	1.4	1.5	8.1	38	2.2	1.3	1.4	15.6
2	1.6	1.0	1.1	5.1	40	6.5	3.9	4.4	31.8
3	2.5	1.5	1.7	13.4	41	3.3	2.0	2.2	18.5
5	2.4	1.5	1.6	6.0	43	4.0	2.4	2.7	10.5
8	2.1	1.3	1.4	7.5	44	4.8	2.9	3.2	22.7
9	4.0	2.4	2.7	23.9	45	4.3	2.6	2.9	19.5
10	2.0	1.2	1.3	8.3	46	3.4	2.1	2.3	18.7
11	2.9	1.7	1.9	11.6	47	2.3	1.4	1.6	11.4
12	1.3	0.8	0.9	11.8	48	2.7	1.6	1.8	10.9
14	4.2	2.5	2.8	30.1	49	2.9	1.7	1.9	14.2
15	4.4	2.6	3.0	13.4	50	3.0	1.8	2.0	17.7
16	4.3	2.6	2.9	15.8	51	3.3	2.0	2.2	12.5
19	5.1	3.0	3.4	11.8	52	3.3	2.0	2.2	11.9
20	2.2	1.3	1.4	17.1	55	2.6	1.6	1.8	8.1
21	7.0	4.2	4.7	30.4	57	3.9	2.3	2.6	17.8
22	5.0	3.0	3.4	17.7	59	3.4	2.1	2.3	9.7
24	8.3	5.0	5.5	17.8	60	2.1	1.2	1.4	12.4
25	2.2	1.3	1.5	11.8	61	3.4	2.0	2.3	9.3
26	9.4	5.6	6.3	15.1	62	2.6	1.6	1.7	11.7
28	2.1	1.3	1.4	14.5	63	2.5	1.5	1.7	11.6
29	2.6	1.6	1.8	25.6	64	2.4	1.5	1.6	6.4
30	1.3	0.8	0.9	12.3	67	2.0	1.2	1.4	12.0
31	2.9	1.8	2.0	19.8	68	2.6	1.6	1.8	12.8
32	2.8	1.7	1.9	12.5	69	4.8	2.9	3.2	20.3
33	7.1	4.3	4.8	21.0	71	2.7	1.6	1.8	13.5
35	2.4	1.4	1.6	10.5	72	7.2	4.3	4.8	19.1
37	2.1	1.2	1.4	13.0	73	3.5	2.1	2.4	15.7

TC=Time of concentration, TL=Traveling time,
Tp=Time of max, qp=max discharge

4.0 CONCLUSION

The maximum daily rainfall of stations in Kelantan catchment was analyzed to distinguish flood risk area. Number of effective factors in occurrence of seasonal floods was determined. Kelantan watershed was classified to flood risk area based on potential to produce runoff for different return period using simulated results of runoff. The sub-basin with same concentration time that caused an increase in flood peak, were identified. Obtained results reveal the impact of all the sub-basins on the flow of Sg. Kelantan River, depending to area and physical properties of those.

Acknowledgments

Authors would like to thank and appreciate the department of irrigation and drainage (flood management division) for making data available to support this study.

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