Evaluation of synthetic unit hydrograph methods for the development of design storm hydrographs for Rivers in South-West, Nigeria

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Abstract: This report presents the establishment of appropriate method of synthetic unit hydrograph to generate ordinates for the development of design storm hydrographs for the catchment of eight selected rivers located in the South West Nigeria. Unit hydrographs were developed based on Snyder, Soil Conservation Service (SCS) and Gray methods; while the SCS curve Number method was used to estimate the cumulative rainfall values for storm depth of different return periods. The peak storm hydrographs corresponding to the excess rainfall values were determined based on the unit hydrograph ordinates established. The peak storm hydrograph flows obtained based on the unit hydrograph ordinate determined by Snyder for 20-yr, 50-yr, 100-yr, 200-yr and 500-yr, return period varies from 112.63m^3/s and 13364.30m^3/s, while those based on the SCS varies from 304.43m^3/s and 6466.84m^3/s and those based on Gray varies from 398.06m^3/s and 2607.42m^3/s for the eight watersheds. The analysis shows that the values of peak flows obtained by Gray and SCS methods for five watershed were relatively close, while the values of peak flows obtained by Gray and Snyder methods for two watershed were relatively close and the values of peak flows obtained by Snyder and SCS methods for only one watershed was relatively close. This inferred that SCS method can be used to estimate ordinate required for the development of peak storm hydrograph of different return periods for the river watersheds considered. [Journal of American Science 2009, x(x); xx-xx] (ISSN: 1545-1003).

Keywords: Synthetic unit hydrograph, storm hydrograph, storm duration, River catchment and return periods

1. Introduction

In many parts of the world, rainfall and runoff data are seldom adequate to determine a unit hydrograph of a basin or watershed. This situation is common in Nigeria due to lack of gauging stations along most of the rivers and streams. Generally, basic stream flow and rainfall data are not available for planning and designing water management facilities and other hydraulic structures in undeveloped watershed. However, techniques have been evolved that allow generation of synthetic unit hydrograph. This includes Snyder's method, Soil Conservation Service (SCS) Method, Gray's Method and Clark's Instantaneous Unit Hydrograph Method. The peak discharges of stream flow from rainfall can be obtained from the design storm hydrographs developed from unit hydrographs generated from established methods. Warren et al (1972) described hydrograph as a continuous graph showing the properties of stream flow with respect to time, normally obtained by means of a continuous strip recorder that indicates stages versus time and is then transformed to a discharge hydrograph by application of a rating curve. Wilson (1990) observed that with an adjustment and well measured rating curve, the daily gauge readings may be converted directly to runoff volume. He also emphasized that catchment properties influence runoff and each may be present to a large or small degree. The catchment properties include area, slope, orientation, shape, altitude and also stream pattern in the basin. The unit hydrograph of a drainage basin, according to Varshney (1986) is defined as the hydrograph of direct runoff resulting from one unit of effective rainfall of a specified duration, generated uniformly over the basin area at a uniform rate. Arora (2004) defined 1-hr unit hydrograph as the hydrograph which gives 1 cm depth of direct runoff when a storm of 1-hr duration occurs uniformly over the catchment.

A vast amount of literature exists treating the various unit hydrograph methods and their development. Jones (2006) reported that Sherman in 1932 was the first to explain the procedure for development of the unit hydrograph and recommended that the unit hydrograph method should be used for watersheds of 2000 square miles (5000 km^2) or less. Chow et al (1988) discussed the derivation of unit hydrograph and its linear systems theory. Further more Viessman et al (1989), Wanielista (1990) and Arora (2004) presented the history and procedures for several unit hydrograph methods. Ramirez (2000) reported that the synthetic unit hydrograph of Snyder in 1938 was based on the study of 20 watersheds located in the Appalachian Highlands and varying in size from 10 to 10, 000 square miles (25 to 25000.0 km^2). Ramirez (2000) reported that the dimensionless unit hydrograph was developed by the Soil Conservation Service and obtained from the UH's for a great number of watersheds of different sizes and for many different locations. It was also stated by

Ramirez (2000) that the SCS dimensionless hydrograph is a synthetic UH in which the discharge is expressed as a ratio of discharge, Q, to peak discharge, Q_p and the time by the ratio of time, t, to time to peak of the UH, t_p. Wilson (1990) also reported that in 1938, Mc Carthy proposed a method of hydrograph synthesis but in that same year Snyder proposed a better known method by analyzing a larger number of basins in the Appalachian mountain region of the United States. Ogunlela and Kasali (2002) applied four methods of unit hydrographs generation to develop unit hydrograph for an ungaged watershed. The outcome of the study revealed that both Snyder and SCS methods were not significantly different from each other. Salami (2009) evaluated three methods of storm hydrograph development for the catchment of lower Niger River basin at downstream of Jebba Dam. The methods considered are Snyder, SCS and Gray methods, the statistical analysis, conducted at the 5% level of significance indicate significant differences in the methods except for Snyder and SCS methods which have relatively close values. This study also applied Snyder, SCS and Gray methods to develop unit hydrographs and subsequently used to generate peak storm hydrographs of rainfall depth of various return intervals through convolution. The peak flows obtained can be used for the design of hydraulic structures within the River Catchment.

2. Material and Methods

2.1 Study area

The watersheds of the river under consideration are located in South West Nigeria. Figure 1 is a map of Nigeria showing the location of the River catchment shaded. Rivers Fawfaw, Oba, Awon, Opeki, and Ogunpa are located in Oyo State, while Rivers Osun and Otin are located in Osun State and River Ogun is located in Ogun State.

2.2 Theory on Unit hydrograph methods

Theories on the applied methods of unit hydrographs are described and were used to synthesize the peak runoff. The methods are; Snyder's, Soil Conservation Service (SCS), and Gray methods.

2.2.1 Snyder's method

The method was used to determine the peak discharge, lag time and the time to peak by using characteristic features of the watershed. Ramirez (2000) reported that the hydrograph characteristics are the effective rainfall duration, t_r, the peak direct runoff rate Q_p, and the basin lag time, t_l. From these relationships, five characteristics of a required unit hydrograph for a given effective rainfall duration may be calculated. The five characteristics are the peak discharge per unit of watershed area, q'_p , the basin lag t'_l, the base time, t_b, and the widths, w (in time units) of the unit hydrograph at 50 and 75 percent of the peak discharge.The unit hydrograph parameters are estimated in accordance to Ramirez (2000) and Arora (2004).

Lag time, t_p

$$t_l = C_t\left(L * L_c\right)^{0.3} \qquad (1)$$

where t_l is lag time (hr) and C_t is a coefficient representing variations of watershed slope and storage. (Values of C_t range from 1.0 to 2.2, Arora (2004)). An average value of 1.60 is assumed for this catchment. Equation (1) gives the lag time, t_l for the watershed.

Unit-hydrograph duration, t_r (storm duration)

$$t_r = \frac{t_l}{5.5} \qquad (2)$$

From equation (2) the duration of the storm was obtained. However, if other storm durations are intended to be generated for the watershed, the new unit hydrograph storm duration (t'_r), the corresponding basin lag time ((t'_l) can be obtained from equation (3)

$$t_l^{'} = t_l + \left(\frac{t_r^{'} - t_r}{4}\right) \qquad (3)$$

Peak discharge, Q'_p

The peak discharge (**Q'_p**) was obtained from equation (4)

$$Q_p^{'} = \frac{2.78 * C_p * A}{t_l^{'}} \qquad (4)$$

where C_p is the coefficient accounting for flood wave and storage conditions.(Values of C_p range from 0.3 to 0.93, Arora (2004) with an average of 0.62 is assumed for this catchment).

Base time (days)

The base time was obtained from equation (5)

$$t_b = 3 + 3\left(\frac{t_l^{'}}{24}\right) \qquad (5)$$

The time width W_{50} and W_{75} of the hydrograph at 50% and 75% of the height of the peak flow ordinate were obtained based on equations (6) and (7) respectively in accordance to U.S Army Corps of Engineer (Arora, 2004). The unit of the time width is hr. Also the peak discharge per area (cumec/km^2) is given by equation (8)

$$W_{50} = \frac{5.9}{\left(q_p^{'}\right)^{1.08}} \qquad (6)$$

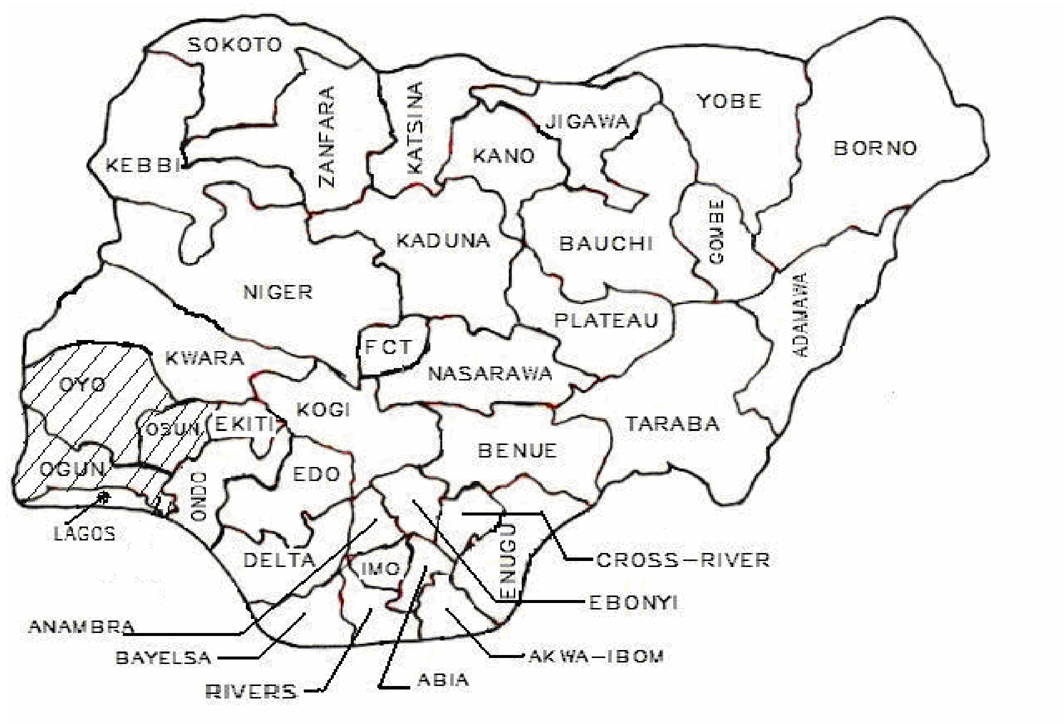

Figure 1 Map of Nigeria showing location of selected river catchments

$$W_{75} = \frac{3.4}{\left(q_p^{'}\right)^{1.08}} \qquad (7)$$

$$q_p^{'} = \frac{Q_p^{'}}{A} \qquad (8)$$

2.2.2 Soil Conservation Service (SCS) method

Raghunath (2006) reported that the US Soil Conservation Service in 1971 used many hydrographs from drainage areas of varying sizes and different geographical locations developed a dimensionless unit hydrograph. The peak discharge and the time to peak can be determined in accordance to Viessman et al (1989), Wanielista (1990), Ramirez (2000), SCS (2002), Ogunlela and Kasali (2002) and Raghunath (2006) as follows;

Peak discharge:

The peak discharge can be obtained through the equation (Ramirez (2000))

$$Q_p = \frac{0.208 * A * Q_d .}{t_p} \qquad (9)$$

where

Q_p = peak discharge (m^3/s)

The estimated values for both the peak discharge and time to peak were applied to the dimensionless hydrograph ratios in accordance to SCS and the points for the unit hydrograph were obtained (Raghunath , 2006) and used to develop the unit hydrograph curve.

2.2.3 Gray's method

The discharge was obtained through the dimensionalizing of the incomplete Gamma function Γ. The equation is given as (Viessman et al 1989; Ogunlela and Kasali, 2002).

$$Q_{t/P_R} = \frac{25.0(g)^q}{\Gamma(q)} \left(e^{-g\left(t/P_R \right)} \right) \left(\frac{t}{P_R} \right)^{q-1}$$

(13)

where

Q_{t/P_R} = percent flow in 0.25 P_R at any given t/P_R value

q and γ = shape and scale parameters, respectively

Γ (q) = the gamma function of q which is equal to (q - 1)!

e = base of natural logarithm

P_R = period of rise (min)

t = time (min.)

Development of unit hydrograph

The Snyder's method was used to compute the lag time, unit hydrograph duration, peak discharge, time base and hydrograph time widths of peak flow by using the watershed characteristics obtained from the topographic map of the River catchment under consideration in accordance to Ramirez (2000) and Arora (2004). The parameters obtained are presented in Table1. The method of US Soil Conservation Service (SCS) for constructing synthetic unit hydrographs was based on a dimensionless hydrograph, which relates ratios of time to ratios of flow (Viessman et al., 1989) and Ramirez (2000). This method requires only the determination of the time to peak and the peak discharge. The calculated values for parameters t_p and q_p were applied to the SCS dimensionless unit hydrograph to obtain the corresponding unit hydrograph ordinates, the estimated unit hydrograph ordinates is presented in Table 2 to 9 based on the values of time to peak discharge (t_p) and peak discharge (q_p) for each river.

Table 1 Parameters for the generation of unit hydrograph (Snyder's method)

River watershed	L (km)	L_c (km)	t_L (hr)	t_r (hr)	Q_p (m^3/s)	T_b (hr)	A (km^2)	S (%)
Faw-Faw	11.80	6.40	5.86	1.07	13.54	89.57	46.00	0.59
Oba	23.50	10.00	8.23	1.50	78.53	96.70	375.00	0.39
Awon	35.60	20.00	11.48	2.09	60.52	106.44	403.00	0.34
Ogunpa	22.87	13.20	8.87	1.61	21.15	98.62	108.85	0.46
Opeki	43.50	20.00	12.19	2.22	81.31	108.57	575.00	0.21
Otin	36.00	16.00	10.77	1.96	76.01	104.31	475.00	0.36
Osun	47.50	15.00	11.48	2.09	175.66	106.44	1170.00	0.21
Ogun	600.00	315.00	61.25	11.14	574.13	255.73	20400.00	0.07

Table 2 Unit hydrograph ordinate for Fawfaw river watershed (SCS method)

T (hr)	0.00	1.05	2.09	3.14	4.18	5.23	6.27	7.32	8.36	9.41	10.45	11.50
Q (m^3/s)	0.00	19.68	45.77	30.21	14.65	7.09	3.43	1.65	0.82	0.41	0.18	0.0

Table 3 Unit hydrograph ordinate for Oba river watershed (SCS method)

T (hr)	0.00	2.09	4.18	6.27	8.36	10.46	12.55	14.64	16.73	18.82	20.91	23.00
Q (m^3/s)	0.00	80.20	186.50	123.09	59.68	28.91	13.99	6.71	3.36	1.68	0.75	0.00

Table 4 Unit hydrograph ordinate for Awon river watershed (SCS method)

T (hr)	0.00	3.02	6.04	9.07	12.09	15.11	18.13	21.16	24.18	27.20	30.22	33.24
Q (m^3/s)	0.00	59.63	138.68	91.53	44.38	21.50	10.40	4.99	2.50	1.25	0.55	0.00

Table 5 Unit hydrograph ordinate for Ogunpa river watershed (SCS method)

T (hr)	0.00	1.92	3.84	5.76	7.69	9.61	11.53	13.45	15.37	17.29	19.21	21.14
Q (m^3/s)	0.00	25.33	58.92	38.88	18.85	9.13	4.42	2.12	1.06	0.53	0.24	0.00

Table 6 Unit hydrograph ordinate for Opeki river watershed (SCS method)

T (hr)	0.00	4.26	8.52	12.78	17.04	21.30	25.56	29.82	34.08	38.34	42.60	46.86
Q (m^3/s)	0.00	60.37	140.39	92.66	44.92	21.76	10.53	5.05	2.53	1.26	0.56	0.00

Table 7 Unit hydrograph ordinate for Otin river watershed (SCS method)

T (hr)	0.00	3.00	6.01	9.01	12.02	15.02	18.03	21.03	24.04	27.04	30.05	33.05
Q (m^3/s)	0.00	70.69	164.40	108.50	52.61	25.48	12.33	5.92	2.96	1.48	0.66	0.00

Table 8 Unit hydrograph ordinate for Osun river watershed (SCS method)

T (hr)	0.00	4.56	9.12	13.67	18.23	22.79	27.35	31.91	36.47	41.02	45.58	50.14
Q (m^3/s)	0.00	114.79	266.95	176.19	85.42	41.38	20.02	9.61	4.81	2.40	1.07	0.00

Table 9 Unit hydrograph ordinate for Ogun river watershed (SCS method)

T (hr)	0.00	50.17	100.34	150.51	200.68	250.85	301.02	351.19	401.36	451.53	501.70	551.87
Q (m^3/s)	0.00	181.84	422.88	279.10	135.32	65.55	31.72	15.22	7.61	3.81	1.69	0.00

The Gray method required the determination of period of rise P_R, and other parameters require in solving equation (13). Other parameters determined are rainfall duration D, the volume of the unit hydrograph V, and the volume of dimensionless graph V_D. The parameters were obtained in accordance to the procedure stated by Viessman et al (1989), Ogunlela and Kasali (2002) and presented in Table 10.

Table 10 Parameter for development of unit hydrograph (Gray method)

River watershed	P_R (hr)	P_R/γ (hr)	D (hr)	Σcfs (10^4)	$V=V_D$ (10^6 m^3)
Faw-Faw	4.85	1.61	1.21	0.95	1.17
Oba	11.94	3.96	2.98	3.13	9.52
Awon	19.26	6.38	4.81	2.09	10.23
Ogunpa	10.70	3.54	2.67	1.02	2.76
Opeki	30.08	9.97	7.52	1.91	14.60
Otin	19.12	6.33	4.78	2.48	12.06
Osun	32.84	10.88	8.21	3.55	29.70
Ogun	739.99	245.18	185.00	2.75	518.00

Development of peak storm hydrographs

The established unit hydrographs ordinates were used to develop the storm hydrographs due to actual rainfall event over the watershed. Peak storm hydrographs for selected return periods (20yr, 50yr, 100yr, 200yr and 500yr) were developed through convolution. The maximum 24-hr rainfall depths of the different recurrence interval for the catchment under consideration are 174.2 mm, 205.0 mm, 232.3 mm, 262.73 mm and 309.0 mm respectively (Olofintoye et al, 2009). The storm hydrograph was derived from a multiperiod of rainfall excess called hydrograph convolution. It involves multiplying the unit hydrograph ordinates (U_n) by incremental rainfall excess (P_n), adding and lagging in a sequence to produce a resulting storm hydrograph. The SCS type II curve was used to divide the different rainfall data into successive equal short time events and the SCS Curve Number method was used to estimate the cumulative rainfall for storm depth of 20yr, 50yr, 100yr, 200yr and 500yr return period. The incremental rainfall excess was obtained by subtracting sequentially, the rainfall excess from the previous time events. The equations that apply to the SCS Curve Number method are given below (SCS, 2002).

$$Q_d = \frac{(P^* - I_a)^2}{P^* + 0.8S} \; for \; P^* > 0.2S \qquad (14)$$

$$Q_d = 0 \; for \; P^* \le 0.2S$$

I_a = initial abstraction $I_a = 0.2S$

$$S = \frac{25400}{CN} - 254 \qquad (15)$$

With the CN = 75 based on soil group B, small grain and good condition, S is estimated as 84.67 mm, while I_a is 16.94 mm. This implies that any value of rainfall less than 16.94 mm is regarded as Zero.

where
P^* = accumulated precipitation (mm)
Q_d = cumulative rainfall excess, runoff (mm)

The storm hydrograph ordinates based on the rainfall depth of desire return periods were estimated from the unit hydrographs. The storm hydrograph peak flows obtained for the watersheds of Fawfaw, Oba, Awon, Ogunpa, Opeki, Otin, Osun and Ogun Rivers based on the three methods of synthetic unit hydrographs and various return periods are presented in Table 10 to 17 respectively.

Table 10 Storm hydrograph peak flows for Faw-Faw River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	112.63	143.70	171.28	203.15	352.34
SCS	304.43	388.06	464.59	556.52	699.89
Gray	398.06	509.24	607.93	721.25	896.87

Table 11 Storm hydrograph peak flows for Oba River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	678.80	866.23	1030.03	1218.99	1510.35
SCS	1240.54	1581.35	1893.19	2267.81	2852.03
Gray	1318.61	1686.91	2013.82	2389.22	2970.98

Table 12 Storm hydrograph peak flows for Awon River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	555.52	707.11	839.52	992.08	1227.17
SCS	922.46	1175.88	1407.77	1686.34	2120.76
Gray	878.37	1123.71	1341.48	1591.55	1979.08

Table 13 Storm hydrograph peak flows for Ogunpa River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	180.44	230.26	273.80	324.02	401.46
SCS	391.89	499.55	598.06	716.40	900.96
Gray	427.21	546.54	652.46	774.08	962.56

Table 14 Storm hydrograph peak flows for Opeki River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	724.84	925.16	1100.29	1302.34	1613.93
SCS	933.81	1190.34	1425.08	1707.08	2146.84
Gray	802.54	1026.70	1225.66	1454.14	1808.21

Table 15 Storm hydrograph peak flows for Otin River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	672.80	858.83	1021.46	1209.10	1498.46
SCS	1093.50	1393.91	1668.80	1999.02	2513.93
Gray	1043.02	13334.35	1592.94	1889.88	2350.05

Table 16 Storm hydrograph peak flows for Osun River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	1558.63	1989.43	2366.10	2800.66	3470.81
SCS	1775.65	2263.46	2709.82	3246.04	4082.25
Gray	1495.47	1913.18	2283.94	2709.69	3369.48

Table 17 Storm hydrograph peak flows for Ogun River watershed (m^3/s)

Methods	Storm return periods				
	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr	500yr, 24hr
Snyder	6018.71	7672.82	9120.66	10790.02	13364.33
SCS	2812.87	3585.63	4292.72	5142.16	6466.84
Gray	1157.25	1480.49	1767.39	2096.86	2607.42

The storm hydrograph peak flows of the same return periods for the catchment of the Rivers under consideration based on the three methods of synthetic unit hydrograph are presented in Figure 2 - 9 respectively. The figures show the relationships between the predicted design storm values using the three methods of synthetic unit hydrograph to generate the required ordinates used for the development of design storm hydrographs.

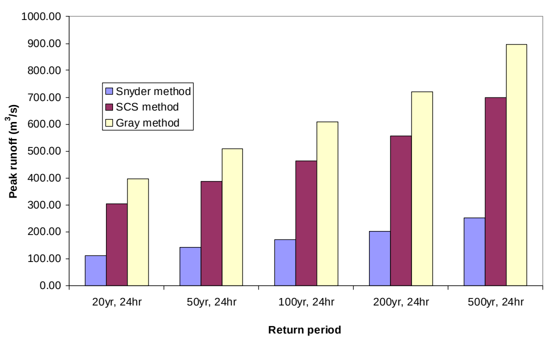

Figure 2 Comparison of peak storm hydrograph for Faw-Faw River

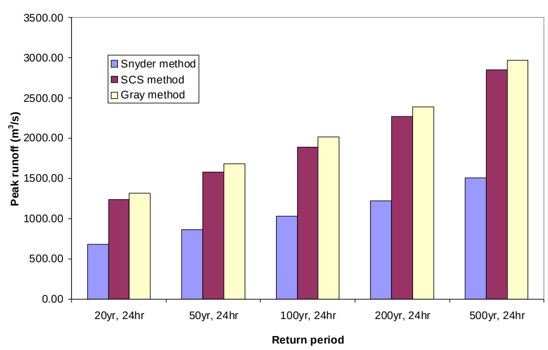

Figure 3 Comparison of peak storm hydrograph for Oba River

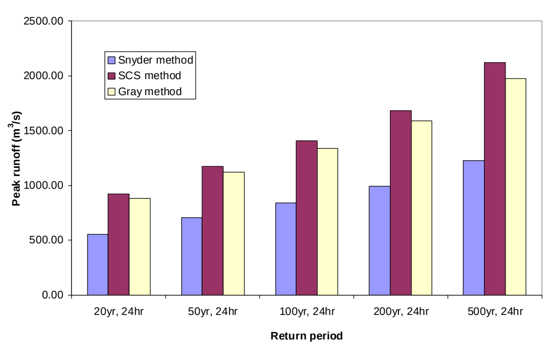

Figure 4 Comparison of peak storm hydrograph for Awon River

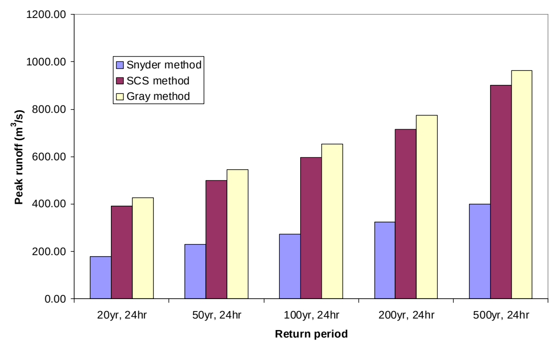

Figure 5 Comparison of peak storm hydrograph for Ogunpa River

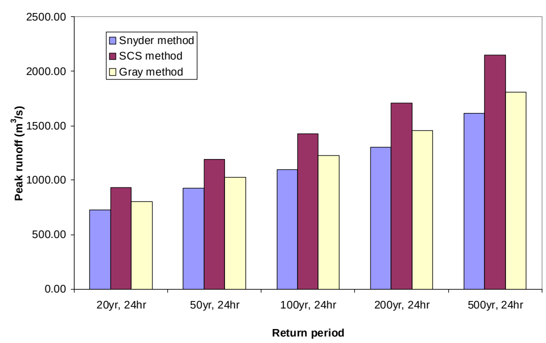

Figure 6 Comparison of peak storm hydrograph for Opeki River

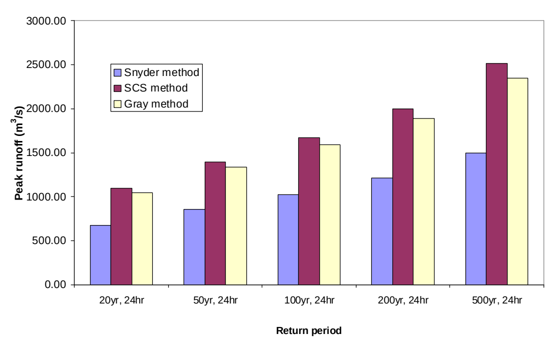

Figure 7 Comparison of peak storm hydrograph for Otin River

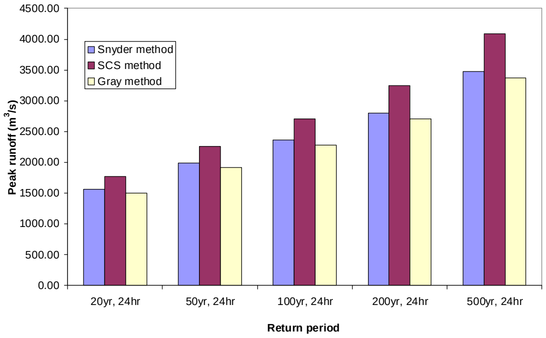

Figure 8 Comparison of peak storm hydrograph for Osun River

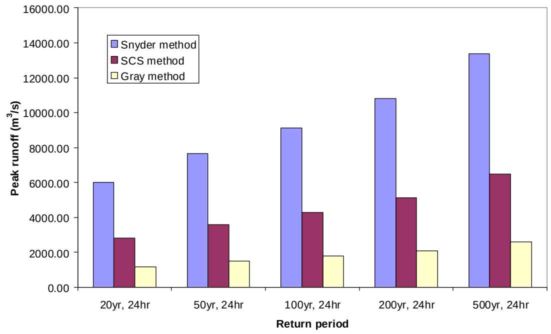

Figure 9 Comparison of peak storm hydrograph for Ogun River

Results and Discussion

Three methods of synthetic unit hydrograph were adopted to determine the ordinates for the development of peak storm hydrograph for Faw-Faw, Oba, Awon, Ogunpa, Opeki, Otin, Osun, and Ogun River watersheds. The methods are Snyder, SCS and Gray. The results from the synthetic unit hydrograph based on the three methods have already been presented in Tables 1 to 9. The storm hydrograph peak flows (m^3/s) for the eight watersheds are presented in Tables 10 to 17 based on Snyder, SCS, and Gray synthetic hydrograph ordinates respectively. The comparison of the storm hydrographs of the same return periods generated based on different synthetic unit hydrographs are presented in Figures 2 to 9 respectively. The results presented in the tables 10 - 17 and figures 2 - 9 shows that for Faw-Faw watershed, the values obtained for Gray method is higher by 71.80% and 23.14% than those of Snyder and SCS method respectively, while the value obtained with SCS method is higher by 63.31% than that of Snyder method. For Oba watershed, the values obtained for SCS method is higher by 45.88% and 5.45% than those of Snyder and Gray method respectively, while the value obtained with Gray method is higher by 48.83% than that of Snyder method. Also for Awon watershed, the values obtained for SCS method is higher by 40.66% and 5.25% than those of Snyder and Gray method respectively, while the value obtained with Gray method is higher by 37.38% than that of Snyder method. Likewise, for Ogunpa watershed, the value obtained for Gray method is higher by 58.02% and 7.81% than those of Snyder and SCS method respectively, while the value obtained with SCS method is higher by 54.46% than that of Snyder method. For Opeki watershed, the values obtained for SCS method is higher by 23.20% and 14.48% than those of Snyder and Gray method respectively, while the value obtained with Gray method is higher by 10.20% than that of Snyder method. For Otin watershed, the values obtained for SCS method is higher by 39.11% and 5.08% than those of Snyder and Gray method respectively, while the value obtained with Gray method is higher by 35.85% than that of Snyder method. For Osun watershed, the values obtained for SCS method is higher by 13.14% and 16.195% than those of Snyder and Gray method respectively, while the value obtained with Snyder method is higher by 3.50% than that of Gray method. For Ogun watershed, the values obtained for Snyder method is higher by 52.06% and 80.63% than those of SCS and Gray method respectively, while the value obtained with SCS method is higher by 59.06% than that of Gray method.

However, the percentage difference shows that for five watershed the values of peak flows obtained by SCS and Gray methods is fairly close (5.08 – 23.14%), while the percentage difference shows that for two watersheds, the values of peak flows obtained by Gray and Snyder method is fairly close (3.50 – 10.20%) and the percentage difference shows that for only one watershed the values of peak flows obtained by Snyder and SCS method to be fairly close. This inferred that Soil Conservation Service (SCS) method is favorably comparable with the other two methods. Based on this observation, it can be summarized that the SCS method can be useful in the generation of unit hydrograph ordinates required for the development of storm hydrograph within the catchment under consideration.

4. Conclusions

It has been noted that the watersheds under consideration have undergone notable eco-hydrological changes due to several developments along their course. This has replaced the natural ground surface, covered with grasses and has influenced its flow pattern. Based on the results obtained, it could be observed that the generation of unit hydrograph through synthetic methods has been found useful and effective. In some cases two methods give very close values. This implies that those two methods are highly efficient in estimating the parameters of the watershed which are required in the development of the unit hydrograph for the catchment considered. Conclusively, SCS method is recommended for use on this watershed since it is most comparable to other methods. The established unit and storm hydrographs can be used to compute the peak flows for the design of hydraulic structures within the catchment. The selection of peak storm hydrograph flows of the desire return period depend on the type of hydraulic structure in mind. For example, peak flow of 100 yr return period is required for the design of bridge, while 20 yr return period can be adopted for drainage culverts and minor bridges. It can also be inferred that synthetic unit hydrograph methods are suitable for the estimation of ordinates for the development of storm hydrograph for rivers that have small watershed, because it was observed that the bigger the watershed area the more the differences between the value obtained with different methods using the same return periods.

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