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A STUDY ON THE PARAMETER ESTIMATION OF SNYDER-TYPE SYNTHETIC UNIT-HYDROGRAPH DEVELOPMENT IN KUM RIVER BASIN

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Abstract: Synthetic unit hydrograph equations for rainfall run-off characteristics analysis and estimation of design flood have long and quite frequently been presented, using the Snyder and SCS synthetic unit hydrograph. The major inputs to the Snyder and SCS synthetic unit hydrograph are lag time and peak coefficient. In this study, the methods for estimating lag time and peak coefficient for small watersheds proposed by Zhao and McEnroe(1999) were applied to the Kum river basin in Korea.

We investigated lag times of relatively small watersheds in the Kum river basin in Korea. For this investigation the recent rainfall and stream flow data for 10 relatively small watersheds with drainage areas ranging from 134 to 902 square kilometers were gathered and used. 250 flood flow events were identified along the way, and the lag time for the flood events was determined by using the rainfall and stream flow data.

Lag time is closely related with the basin characteristics of a given drainage area such as channel length, channel slope, and drainage area. A regression analysis was conducted to relate lag time to the watershed characteristics. The resulting regression model is as shown below:

$$T_{lag} = 0.0044\left(\frac{L_c}{\sqrt{S_c}}\right)^{1.2282}$$

In the model, Tlag is the lag time in hours, Lc is the length of the main river in kilometers and Sc is the equivalent channel slope of the main channel. The coefficient of determination (r^2) expressed in the regression equation is 0.846.

The peak coefficient is not correlated significantly with any of the watershed characteristics. We recommend a peak coefficient of 0.60 as input to the Snyder unit-hydrograph model for the ungauged Kum river watersheds

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Key Words: synthetic unit hydrograph, Snyder type, lag time, peak coefficient

1. INTRODUCTION

The rainfalls in the Kum river basin, the target area of this study, are usually local downpours caused by typhoons, which cause concentrated damage to specific areas along the watershed. Such torrential rainfalls at the basin have not only caused damage to the main channel of the basin but have also resulted in great loss of human life and property in the smaller channels around the basin. Therefore, it seems necessary to estimate the discharge of the area via unit hydrograph to determine the hydrograph and design flood when designing any hydraulic structures for the Kum river basin area. However, setting up the unit hydrograph for the Kum river basin can be a complicated task, taking into consideration that we have little hydrologic records to figure out the rainfall-runoff process of the area.

Moreover, the discharges measured for hydraulic structure construction at those ungauged basins of the river cannot be expected to be highly accurate. Synthetic unit hydrograph is a method used to establish discharges at ungauged basins, in which the parameters are induced from the same basins for unit hydrograph estimation using the correlation between the physical characteristics and rainfall-runoff process of the basin to estimate the discharge. Thus, to estimate the discharge for those ungauged basins, the parameters used for unit hydrograph estimation such as lag time and peak coefficient is required.

Zhao and McEnroe (1999) concluded that the key input to Snyder-type synthetic unit-hydrogragh model are the lag time and the peak coefficient. They computed lag times and peak coefficient for more than 200 flood events at nineteen stream-gauging station in Kansas and and they related the average lag times to watershed characteristics by regression analysis. The results of their study show that the two most significant explanatory variables are the length and average slope of the stream and the recommended regression equation for lag time has a standard error of estimated 20%.

In this study we collected the last three years' rainfall and river stage records (1997-1999) at the major gauging stations along the Kum river basin, and computed the lag time and peak coefficient from hydrograph to establish a series of equations, then related them with the physical characteristics of the gauged basins in order to achieve our goal - to be able to establish the synthetic unit hydrograph parameters with the physical characteristics of the basin.

Fig. 1. The Kum River Basin and Gauging Stations

In order to establish lag time (which is required to determine the synthetic unit hydrograph on the basis of the Snyder and SCS methods) and peak coefficient (a significant input to the Snyder type of synthetic unit hydrograph)

graph) using the physical characteristics of the basin, the correlation between those parameters (lag time and peak coefficient, and the physical characteristics of the topographical components) at the gauging stations has been analyzed to determine discharge for the construction of hydraulic structures in the basin. The Kum river basin and the gauging stations may be specified as in Fig 1.

2. LAG TIMES AND PEAK COEFFICIENTS FOR GAGED WATERSHEDS

In this study, three simple rainfall events were selected from each rainfall gauge and the lag times were determined from the hydrograph on the basis of the rainfalls. The analysis was performed under the supposition that the rainfall and discharge in an hour has an equal distribution rate, so although shorter time intervals for each gauged datum will provide better efficiency the gauging interval at the Kum river basin was fixed to an hour.

Lag time can be defined in a couple of ways. In this study, lag time has been defined as the time interval of peak flow in the center of a rainfall hyetograph.

To estimate lag time, the rainfall data from each rainfall gauge has been collected to compute the basin mean precipitation. Also, the hourly water levels and the rating curves at each stage gauging stations are collected for total runoff hydrograph at each subbasin. Lag time can be calculated from this hydrograph, and we applied this method to each of the rainfall events for the respective basins to acquire an arithmetic

Table 1. Lag Times for Each Rainfall in the Respective Areas

Stage gauging station	Date	Lag time (T_{lag}), hr	Mean Lag time (T_{lag}), hr
Song-chon	97. 05. 07	13.75	13.44
	97. 11. 28	12.55	
	99. 05. 03	14.02	
Cheong-Sung	97. 05. 07	19.28	14.85
	97. 11. 28	13.15	
	98. 05. 11	12.12	
Cheong-Ju	98. 07. 31	4.41	5.60
	99. 06. 16	6.67	
	99. 09. 23	5.73	
Ok-san	98. 04. 05	9.53	10.09
	98. 05. 11	10.86	
	98. 07. 31	10.05	
Woo-sung	97. 11. 12	5.88	6.87
	99. 06. 16	7.88	
	99. 07. 09	6.84	
Ku-ryong	97. 11. 12	11.97	12.62
	98. 05. 11	15.90	
	98. 06. 16	9.98	
Non-san	99. 06. 25	7.64	8.06
	99. 06. 23	8.65	
	99. 10. 10	7.89	

mean.

From the result, we found the Hoe-deok, Buk-il, and Woo-gon gauging stations had unstable results because the discharge of Hoe-deok gauging station is changing according to the operation of rubber dam which is located 500m above. Also in case of Buk-il it was unable to separate the single rainfall event because of its large basin area. So we had to exclude those results from this study to remove unstable factors in reliability. Again, among the runoff hydrographs for the remaining 7 gauging stations, 3 hydrographs for simple rainfall events were selected. The resulting lag times for each station are shown below in Table 1.

The arithmetic mean calculated on the basis of the lag times (t_{lag}) for each subbasins showed that the mean lag time of the station was from 6.87hr to 14.85hr, and the specific factors in each of the basins seemed to cause the differences.

In a unit hydrograph model, peak coefficient (Cp) determine the shape of the unit hydrograph. There are many formulas suggested to get the peak coefficient. However, since the value of C1 may vary in the formula, we modified the original formula in the process. Peak coefficient Cp is a dimensionless variable defined in formula 1a and 1b.

$$q_p = \frac{c_l \cdot c_p}{t_{lag}} \tag{1a}$$

$$c_p = \frac{q_p \cdot t_{lag}}{c_l} \tag{1b}$$

q_p in the formula represents peak discharge

Table 2. Peak Coefficient for Each Rainfall in the Respective Areas

Stage gauging station	Date	Peak coefficient (Cp)	Mean Peak coefficient (Cp)
Song-cheon	97. 05. 07	0.80	0.78
	97. 11. 28	0.70	
	99. 05. 03	0.83	
Cheong-sung	97. 05. 07	0.70	0.56
	97. 11. 28	0.46	
	98. 05. 11	0.52	
Cheong-ju	98. 07. 31	0.72	0.75
	99. 06. 16	0.75	
	99. 09. 23	0.78	
Ok-san	98. 04. 05	0.49	0.36
	98. 05. 11	0.31	
	98. 07. 31	0.30	
Woo-sung	97. 11. 12	0.30	0.31
	99. 06. 16	0.35	
	99. 07. 09	0.28	
Ku-ryong	97. 11. 12	0.73	0.66
	98. 05. 11	0.68	
	98. 06. 16	0.58	
Non-san	99. 06. 25	1.07	0.80
	99. 06. 23	0.43	
	99. 10. 10	0.89	

for unit basin area (cms/km^2), C1 is 2.75, and t_{lag} represents lag time (hr)(Larry W. Mays, 1996). In Snyder's unit hydrograph, peak discharge was directly proportional to peak coefficient.

Through this we arrived at the peak discharges in hydrograph for each selected rainfall events. Then we calculated the peak coefficients for each rainfall and induced the arithmetic mean applying the previously determined time lag (t_{lag}) and basin area to the formula 1a and 1b. The results of this process are as shown in Table 2.

The analysis on the peak coefficient (C_p) showed that the mean peak coefficient of the Kum river basin ranges from 0.31 to 0.80. Woo-sung and Ok-san had especially low peak coefficients compared to other areas. This may be because those two symmetric areas in the basin have different rainfall-runoff process from the other locations.

3. CORRELATION ANALYSIS

Lag time has much to do with the physical and climatologically characteristics of the basins. In this study, we employed SAS ver. 6.2 to figure out which of the physical characteristics of the basin has a close relationship with lag time. The physical characteristics of each basin and their peak coefficient values were used as independent variables in this correlation analysis. Also, we estimated correlation coefficients between those physical characteristics to figure out the relationship between these physical characteristics and lag time.

To figure out the relationship between the lag time estimated in this study and the selected representative topographical characteristics [i.e., basin area (A), basin length (L), channel length (L_c), length along the mainstream from outlet to the point closest to the basin centroid (L_{ca}), basin shape factor (K_f), channel slope (Sc), equivalent gradient (S_e), and basin slope (B_s)], we performed a correlation analysis taking each of those components as independent variables. Also, we determined correlation coefficients in order to explain the relationship through correlation analysis. The correlation coefficients for each subbasins were as shown below in Table 3.

The correlation analysis result showed that lag time (Tl_{ag}) has a positive correlation with the basin area, basin length, length along the mainstream from outlet to the point closest to the

Table 3. Correlation Coefficient Between Lag time and Topographical Characteristics

	T_{lag}	A	L	Lc	Lca	K_f	Sc	Se	Bs
T_{lag}	1.000								
A	0.594	1.000							
L	0.820	0.844	1.000						
Lc	0.820	0.841	0.999	1.000					
Lca	0.529	-0.095	0.355	0.358	1.000				
K_f	-0.461	0.221	-0.332	-0.337	-0.763	1.000			
Sc	0.585	0.388	0.454	0.456	0.241	-0.113	1.000		
Se	-0.353	0.387	0.054	0.051	-0.845	0.534	-0.309	1.000	
Bs	-0.324	-0.372	-0.114	-0.109	0.367	-0.440	-0.535	-0.100	1.000

basin centroid, and channel slope, and a negative correlation with the basin shape factor, equivalent gradient, and basin slope. In general, channel slope has a negative correlation with lag time. Therefore, the result of our analysis where the channel slope had a positive correlation with lag time means that the channel slope (S_c) defined in this study may not be expressing well enough the specific features of the basin.

Basin length (L) and channel length (L_c) are the two factors carrying the strongest correlation with lag time. In the result, the correlation coefficient of 0.820 reconfirms surely that basin length and channel length have a very strong positive correlation, in which the lag time increases where basin length or channel length extends.

In this study, however, we assumed that lag time has a stronger correlation with channel length (L_c) than with basin length (L), taking into consideration that there may be many variables in the runoff process of the places where the channel starts from the watershed of a specific basin area.

Both the channel length and channel slope are important variables in explaining lag time. In the Snyder-type formula, the most commonly used method to estimate lag time, lag time is calculated with only channel length (L_c) and length along the mainstream from the outlet to the point closest to the basin centroid (L_{ca}). To make up for this certain instability in the existing Snyder-type formula, we performed a correlation analysis inducing the following correlation for the purpose of obtaining lag time from the channel length (L_c) and length of the main stream (L_{ca}).

The rational formula used for the calculation of peak flood caused by a certain fixed intensity is shown below in Formula 2. In the formula, the rainfall intensity (I) comes from the rainfall of the relative basin, and the time of concentration (t_c) is calculated by the empirical formula for the time of concentration. General empirical formula commonly used in this process is as shown below in Formula 3.

$$Q = 0.2778CIA \qquad (2)$$

In the formula above, "Q" is the peak discharge (cms) at the basin gateway, "I" is the rainfall intensity (mm/hr) with 1-hour duration, and "A" is the basin area.

$$t_c = a \times \frac{L^b}{S^c} \qquad (3)$$

In Formula 3, "a", "b", and "c" are specific coefficients for the formula, "L" meaning channel length (L_c), and "S" stands for the mean slope of the basin where the deviation in level to the height of the farthest point (H) along the mainstream is divided by the channel length (H/L_c).

Shown below is a Manning's formula for mean velocity, which is used to express stream velocity.

$$v = \frac{1}{n} \times R^{2/3} \times S^{1/2} \qquad (4)$$

In the formula above, "n" stands for roughness coefficient, "R" is used to express hydraulic radius, and "S" is channel slope.

In the formulas above (Formula 2, 3, and 4.), time of concentration (t_c) is proportional to channel length (L_c), and time of concentration (t_c) is inversely proportional to the square of channel slope (S).

When time of concentration (t_c) and lag time is in direct proportion, the lag time has the correlation of "Tlag$\propto$ $L_c/\sqrt{S_c}$ " with equivalent gradient (S_e) which expresses rather accurately the channel slope.

We added "$L_c/\sqrt{S_c}$", the correlation between channel length and channel slope, to the lag time (Tl_{ag}) estimated in this study and the physical characteristics of the target area to arrive at the correlation coefficient. Table 4 Shows the resulting correlation coefficient values.

According to the result, the correlation coefficient for the correlation between channel length and channel slope was 0.917, which means lag time has a strong relationship with the correlation between channel length and channel slope, which in turn means the lag time will increase as the correlation between channel length and channel slope becomes stronger.

The correlation between lag time and those physical characteristics of the target area shown above showed that the correlation coefficient of the correlation between channel length and channel slope ($L_c/\sqrt{S_c}$, 0.917) was even stronger than that of the correlation between lag time and channel length (0.820), which was the highest numeric in the former calculation where the correlation was induced using only lag time and physical characteristics of the target area themselves. This proved that lag time has a stronger correlation with the correlation between channel length and channel slope ($Tl_{ag}\propto$ $L_c/\sqrt{S_c}$) rather than with its more simple and direct relationship with channel length (L_c).

In this study, in order to see if peak coefficient has any correlation with lag time (Tl_{ag}) and/or other physical characteristics of the

Table 4. The Correlation Coefficient for the Correlation Between Channel Length and Channel Slope.

	T_{lag}	$Lc/\sqrt{S_c}$	A	L	Lc	Lca	K_f	Sc	Se	Bs
T_{lag}	1.000	0.917	0.594	0.820	0.820	0.529	-0.461	0.585	-0.353	-0.324
$Lc/\sqrt{Se}$	0.917	1.000	0.528	0.855	0.856	0.739	-0.602	0.596	-0.465	-0.073

Table 5. The Correlation of Peak Coefficient with Lag Time (T_{lag}) and/or Other Physical Characteristics of the Gauged Basin

	C_p	T_{lag}	A	L	Lc	Lca	K_f	Sc	Se	Bs
C_p	1.000									
T_{lag}	0.098	1.000								
A	0.275	0.594	1.000							
L	0.291	0.820	0.844	1.000						
Lc	0.291	0.820	0.841	0.999	1.000					
Lca	-0.484	0.529	-0.095	0.355	0.358	1.000				
K_f	-0.128	-0.461	0.221	-0.332	-0.337	-0.763	1.000			
Sc	-0.045	0.585	0.388	0.454	0.456	0.241	-0.113	1.000		
Se	0.693	-0.353	0.387	0.054	0.051	-0.845	0.534	-0.309	1.000	
Bs	-0.113	-0.324	-0.372	-0.114	-0.109	0.367	-0.440	-0.535	-0.100	1.000

gauged basin, we performed a correlation analysis between the peak coefficient for each area and lag time (T_{lag}) and/or other physical characteristics formerly defined within this study as shown below in Table 5.

According to the result, peak coefficient was positively proportional to lag time, basin area (A), basin length (L), channel length (L_c), and equivalent gradient (S_e), but length along the mainstream from the outlet to the point closest to the basin centroid (L_{ca}), channel slope (S_c) and basin slope(B_s) were negatively proportional to the peak coefficient. However, the value for correlation of the peak coefficient with lag time and/or physical components of the basin was rather minor, which proved that there is only a weak correlation between them.

4. REGRESSION ANALYSIS

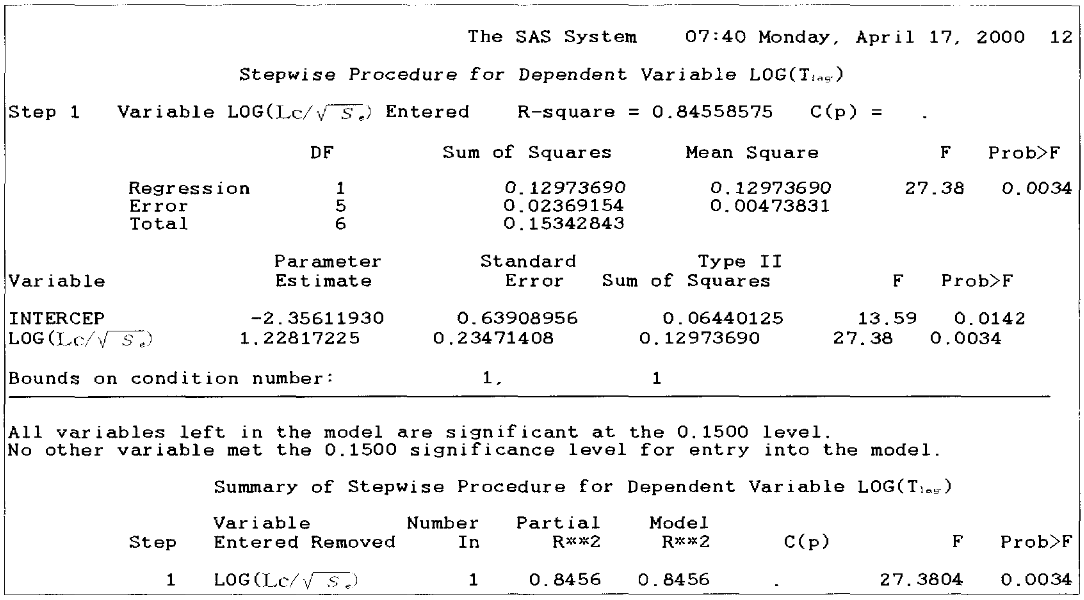
On the basis of the correlation between lag time (T_{lag}) and physical and topographical components and/or channel length and channel slope ($L_c/\sqrt{S_c}$) which have formerly been established in this study, we developed a formula for lag time estimation via a regression between the lag time and physical components which can be applied to the ungauged basin of the Kum river basin.

The selection of an independent variable is the most important issue in model development; the existence of more than three independent variables may make the regression analysis an extremely complicated task. Moreover, in cases where those independent variables have a specific correlation between themselves, the model will ultimately be quite unstable. That is to say, a random and casual regression analysis will mean almost nothing in most cases.

To develop a unique formula for our regression analysis, we used the statistics and analysis software, SAS, just like we did for our correlation analysis.

For this regression analysis, we set the lag time (T_{lag}) in the former process as a dependent

Table 6. The Result of Regression Analysis via Stepwise Method



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                        Stepwise Procedure for Dependent Variable LOG(Tlag)

Step 1   Variable LOG(Lc/√Se) Entered     R-square = 0.84558575    C(p) =    .

                               DF        Sum of Squares      Mean Square          F    Prob>F

          Regression            1           0.12973690        0.12973690      27.38    0.0034
          Error                 5           0.02369154        0.00473831
          Total                 6           0.15342843

                          Parameter        Standard          Type II
Variable                   Estimate           Error    Sum of Squares          F    Prob>F

INTERCEP                -2.35611930       0.63908956       0.06440125      13.59   0.0142
LOG(Lc/√Se)              1.22817225     0.23471408      0.12973690      27.38   0.0034

Bounds on condition number:              1,            1
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All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

                    Summary of Stepwise Procedure for Dependent Variable LOG(Tlag)

                    Variable           Number    Partial     Model
              Step  Entered Removed        In       R**2      R**2      C(p)          F    Prob>F

                 1  LOG(Lc/√Se)             1     0.8456    0.8456         .      27.3804   0.0034
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variable. Then we set the physical characteristics of the basin [i.e., basin area (A), basin length (L), channel length (L_c), length along the mainstream from the outlet to the point closest to the basin centroid (L_{ca}), basin shape factor (K_f), channel slope (S_c), equivalent gradient (S_e), and basin slope (B_s) and the correlation between channel length and channel slope ($L_c/\sqrt{S_c}$)] as independent variables respectively. In order to eliminate errors in the regression analysis and increase the reliability of our model, we continued regression analyses repeatedly using the stepwise method until an appropriate model was produced to define a lag time formula.

Since the rainfall-runoff, prior to the regression analysis, does not take place algebraically but exponentially, we performed our regression analysis-applying Log transformation to each variable in order to define a lag time formula in an exponential function. The result of stepwise analysis was as shown above in Table 6.

The result of regression analysis via stepwi method shown above in Table 6, satisfied th significant level of 0.15 in Step 1, and the coefficient of determination (r^2) was defined as 0.846. The formula for lag time calculation through this regression analysis was defined as shown below in Formula 5a. In this study, we expressed it in the form of an exponential equation, which is expressed in Formula 5b.

$$\mathrm{LogT}_{lag} = -2.35611930 + 1.22817225\left(\mathrm{Log}\left(\frac{L_c}{\sqrt{S_e}}\right)\right) \tag{5a}$$

$$T_{lag} = 0.0044\left(\frac{Lc}{\sqrt{S_e}}\right)^{1.2282} \tag{5b}$$

The coefficient of determination (r^2) expressed in the regression equation was 0.846, which was quite a high degree. But the number of data which was used in this regression analysis is not enough to guarantee the reliability of

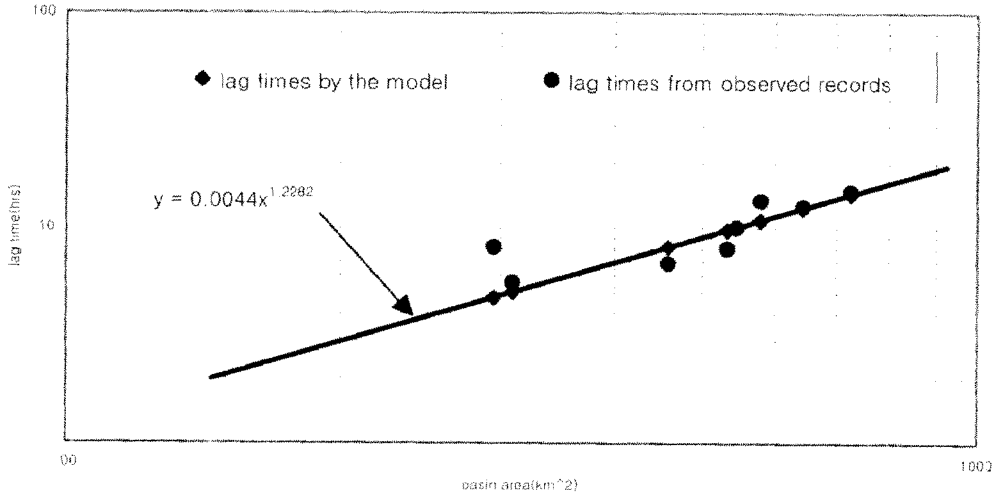

Fig. 2. The Comparison of the Lag Times obtained from the Observed Records and the Lag Times Estimated by the Developed Model

the regression equation.

Then, to figure out the correlation between the induced formulas and lag time, we set two physical components of each subbasins selected for this study and estimated directly from the gauged basins- channel length and channel slope- as input variables to estimate lag time. Fig. 2 shows the comparison of the lag times obtained from the observed records and the lag times estimated by the developed model.

5. ANALYSIS OF PEAK COEFFICIENT

Earlier in this study, we concluded that peak coefficient has little to do with lag time and the physical/topographical characteristics of the basin area. According to this result, we performed a simple frequency analysis, presuming that peak coefficient correlates only with the effluence caused by rainfalls at the basin area and nothing else.

The mean peak coefficient of the Kum river basin was between 0.31 and 0.80, and the mean coefficient for each subbasin showed an average of 0.60, a standard deviation of 0.19. Peak coefficient did not have a strong correlation with the specific features of the basin area, and it seems that peak coefficient can be estimated on the basis of the runoff caused by rainfalls at each subbasin only. The frequency distribution of peak coefficient in relation to each gauged basin is as shown below in Fig. 3.

6. CONCLUSION

In this study, we developed a series of formulas for lag time estimation on the basis of the physical characteristics of the basin area to obtain lag time, the parameter required in the estimation of synthetic unit hydrograph and the discharge estimation by via the Snyder and SCS methods. Also we were able to developed a unique synthetic unit hydrograph and establish a higher discharge for the Kum river basin. In addition, we verified our own lag time estimation formulas by comparing the lag times obtained from the observed records and the lag times estimated by the developed model. The result of this study may be summarized as follows:

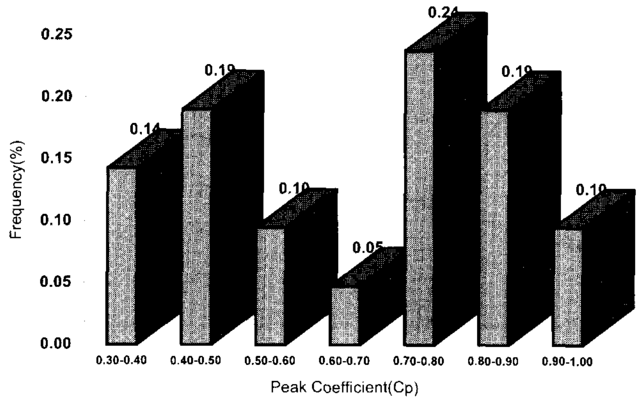

Fig. 3. The Frequency Distribution of Peak Coefficient Along the Kum River Basin

1. The lag time at the Kum river basin was proved to have a close correlation with the relationship between channel length and channel slope ($Lc/\sqrt{S_c}$). The lag time estimation formula on the basis of this result may be shown as:
   The value of coefficient of determination (r^2) between the two components was 0.846.
2. The analysis on the peak coefficient (C_p) of the each subbasin showed that it has nothing to do with the physical characteristics of the basin area. Also, we recommend a peak coefficient of 0.60 as input to the Snyder unit-hydrograph model for ungaged basin of Kum river watersheds.
3. The unstable factors of the existing Snyder-type formula could be improved partially by estimating lag time through regression analysis on the basis of channel length and channel slope.

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