〈論　　文〉

남강댐 유역에 있어서 강우분포의 변화
Rainfall Variations in the Nam River Dam Basin

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Abstract□ An investigation into the rainfall variability in time and space in the Nam River dam basin of Korea was made with use of the coefficient of variation and the correlation coefficient. The Nam River dam basin is a small mountainous watershed where the wind direction and orography are the dominant influences on the pattern and distribution of rainfall. It was found that the characteristics of rainfall distribution vary with elevation, position, wind direction. And in the three directions considered, it was found that there is the related formulation dependent on the distance between two stations. The results of this study on the temporal and spatial characteristics of rainfall can be used in the design of raingauge networks, hydrological forecasting, and so on in the Nam River dam basin.

요　지 : 산악지역에서의 강우의 시공간적 분포양상은 풍향, 지형, 고도 등의 영향을 많이 받게 된다. 본 논문에서는 소규모의 복잡한 산악지역인 남강댐 유역에서의 시공간적인 강우분포양상을 변동계수와 상관계수를 주로 이용하여 분석하였다. 강우의 분포는 고도, 지형의 위치, 풍향 등에 따라 뚜렷하게 변화함을 발견할 수 있었다. 그리고 고려한 세 가지 방향에 있어서 두 관측소간의 거리에 따른 강우량의 상관성을 정식화할 수 있었다. 본 연구의 결과들은 남강댐 유역과 같은 소규모 산악유역에서의 강우계측망의 설계와 홍수예경보, 기타 다른 여러 가지 목적으로 사용될 수 있을 것이다.

I. Introduction

An understanding of precipitation and its distribution in time and space is essential for proffer and cost-effective design of many engineering structures. Information on the distribution of rainfall is important in a variety of applications, such as design of raingauge networks, hydrological forecasting, watershed modeling, etc. Factors that affect rainfall distribution include wind speed and direction, air temperature, humidity, air pressure, elevation, slope, barriers and orientation, continentality, and the direction, strength and frequency of jet streams. There have been many studies on the effects of these factors on rainfall distribution (Oki et al., 1991).

The relation between precipitation and elevation has been widely investigated(Danard, 1971; Sevruk, 1974; Ballantyne, 1983; Osborn, 1984; Schumaker et al., 1984; Puvaneswaran et al., 1991). Empirical studies on mean annual precipitation changes with elevation have shown that on windward slopes in temperate latitudes, the relationship is positive at least up to 3000m though it may not always be linear(Ballantyne, 1983). The effects of wind speed and wind di-

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rection have also been reported(Huff and Shipp, 1969; Sevruk, 1974; Sharon, 1979; Jayawardena and Peart, 1989; Sivakumar and Hatfield, 1990; Puvaneswaran and Smithson, 1991; Merva et al, 1971). Several studies also have been carried out on the relation between rainfall distribution and the orographic and climatic factors(Corradini, 1985; Merva et al., 1971; Peck, 1972). It is known that the areal variability of rainfall is affected by the nature and orientation of terrain, and that it is necessary to establish a dense network in mountainous areas than flat ones.

Four major factors determining rainfall distribution in mountainous areas can be identified as the speed of ascending air, water vapor supply, wind direction and wind speed. Wind speed is mainly related to rainfall intensity and is less related to its distribution(Oki et al., 1991). Water vapor supply can be regarded as a sufficient conditions at a storm event. Therefore, for a qualitative discussion, rainfall distribution can be estimated from just wind direction and the area of ascending air(Oki et al., 1991).

Although several studies on rainfall distribution for various topographic areas have been undertaken for designing raingauge networks and hydrological modeling, there are unique characteristics of rainfall pattern and its distribution affected predominantly by wind direction and orography. Because of these peculiar characteristics, the results of one study are not applicable to all of the areas.

This paper investigates rainfall variability in the Nam River dam basin of Korea with use of the coefficient of variation and the correlation coefficient. This is a small but complicated mountainous watershed. The Nam River dam was originally constructed in 1969 and is now under reconstruction as a reinforcement dam. Planning is underway to reset the raingauge network in this small, rugged, mountainous basin in order to improve hydrologic information for operating hydraulic structures within the basin.

Ⅱ. Study Area

The Nam River dam basin, as shown in Figure 1, lies on the south part of Korean peninsula, has 1498.4mm of mean annual precipitation, and is 2285㎢ in drainage area. Its elevation range is 32～1915m, and its average elevation is up to 422.8m or more as shown in Table 1. The Nam River basin lies from the east of 127°30'E to the west of 128°15'E, and from the south of 35°N to the north of 35°45'N. Table 1 gives area by elevation. The rainfall amount of rainy season is up to 80～90% of the yearly total and the average number of rainy days is about 80 days a year(Korea Water Resources Cooperation, 1992). Figure 2 shows a three-dimensional view of the topography of the Nam River dam basin and its vicinity. There are significant differences in directions of wind due to change of elevation over the basin. In the April ～July period, most of the rainfall is due to Baiu (Jangma) front. However, in the August ～September period, most of the rainfall is due to tropical cyclones, typhoons(Kim, 1976).

Ⅲ. Data

There are fourteen raingauging stations in the Nam River dam basin. Table 2 lists the rainfall stations used in this study and their location. The average elevation of all the stations is 285m. These stations may be divided according to elevation: four stations in the high elevation (higher than 400m)area, six stations in the medium elevation(from 100 to 400m)area, and four stations in the low elevation(below 100m)

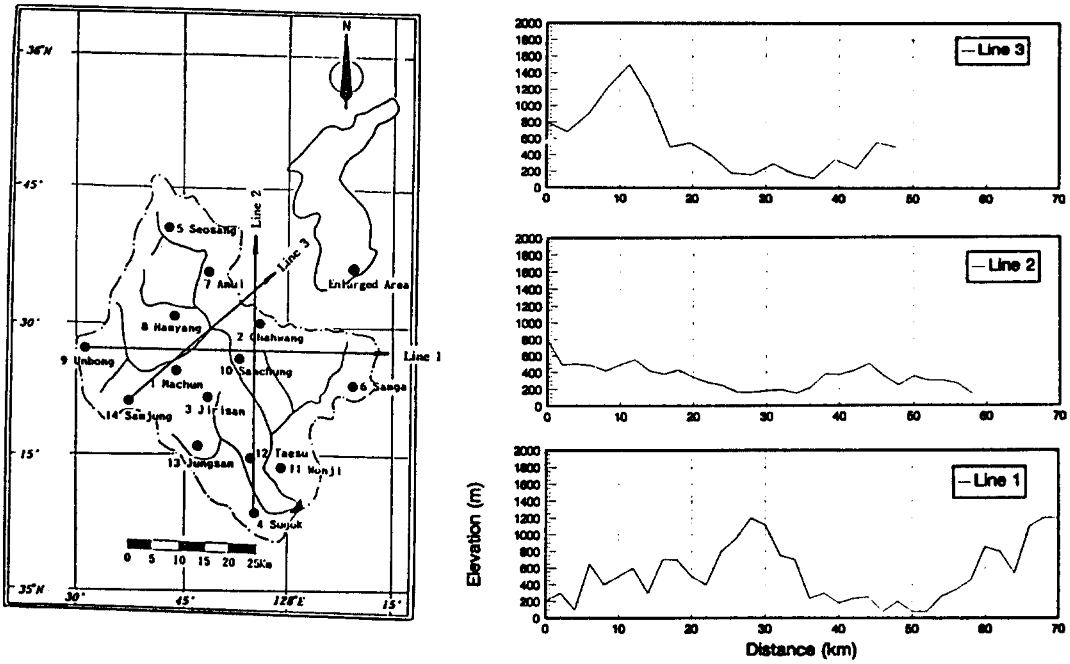

Figure 1. Study area and the location of raingauging stations and cross section of three lines across the Nam River dam basin

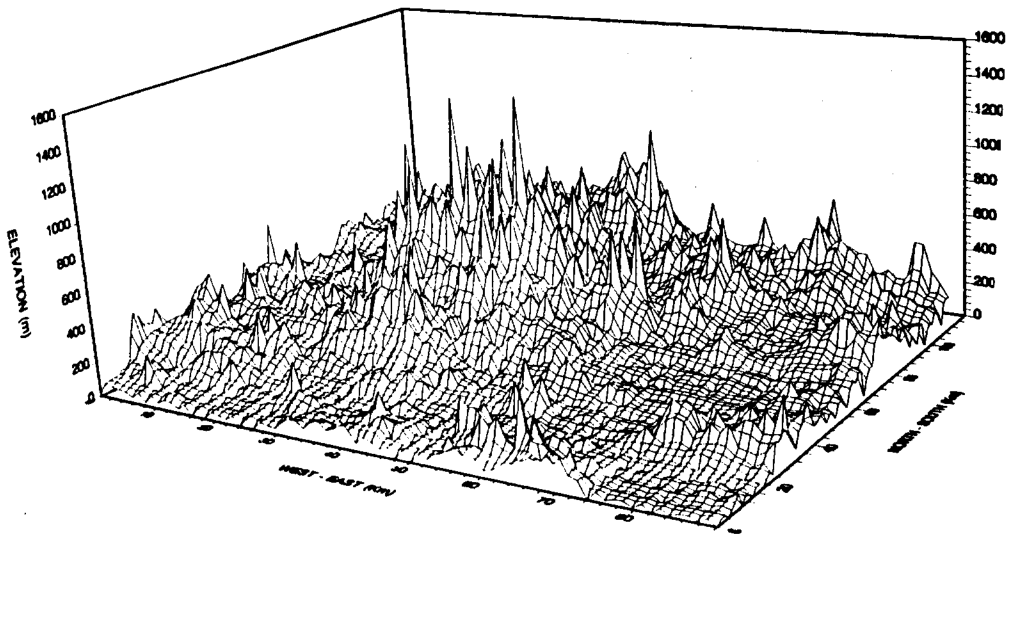

Figure 2. Three-dimensional view of the topography of the Nam River dam basin and its vicinity

Table 1. Area by elevation in the Nam River dam basin

Elevation(m)	0–100	100–200	200–400	400–600	600–800	800 or more
Area(㎢)	228.9	465.9	546.8	477.5	271.9	294.0
Ratio(%)	10.0	20.4	23.9	20.9	11.9	12.9
Accumulated Area	2285.0	2056.1	1590.2	1043.4	565.9	294.0
Ratio(%)	100.0	90.0	69.6	45.7	24.8	12.9

Table 2. Raingauge network in the Nam River dam basin

No.	Station	Latitude(E)	Longitude(N)	Altitude(m)	Position
1	Machun	127° 39′	35° 24′	300.0	windward
2	Chahwang	127 56	35 28	340.0	leeward
3	Jirisan	127 45	35 46	340.0	windward
4	Sugok	127 56	35 11	80.0	windward
5	Seosang	127 42	35 42	450.0	leeward
6	Samga	128 07	35 24	80.0	leeward
7	Anui	127 49	35 37	230.0	leeward
8	Hamyang	127 43	35 31	180.0	leeward
9	Unbong	127 30	35 28	500.0	leeward
10	Sanchung	127 53	35 25	130.0	windward
11	Wonij	127 59	35 18	50.0	windward
12	Taesu	127 54	35 16	90.0	windward
13	Jungsan	127 45	35 18	620.0	windward
14	Samjung	127 38	35 21	600.0	windward

area. Eight of these stations are located on windward side and six stations on leeward side, based on the consideration of the prevailed wind direction. The basin covers an area of 2285㎢, about 70% of which is mountainous, with an average of one raingauge for each 163㎢ (Korea Water Resources Corporation, 1992). Rainfall records for the fourteen stations are shown in Figure 1 were available for 27 years. These were obtained from the annual report of hydrological investigation of Korea by the Ministry of Construction in Korea. Figure 1 shows three directions that will be used for an additional analysis of the spatial characteristics of rainfall.

Ⅳ. Temporal Rainfall Distribution

Variations of precipitation with time may be considered either in relation to precipitation regimes, the regular, perhaps predictable, trends exhibited by annual, seasonal or short-term totals, or in relation to the statistical probability of a given areal pattern, or individual total or intensity being repeated within a certain period (Commonwealth Scientific and Industrial Research Organization, 1976). Studies on variability have been made for either (i) the determination of the expectation of rainfall under specified conditions; and/or (ii) the comparison of variabilities within a given region, or between regions, for comparative climatology.

There are several ways of describing the variability : the range, the standard deviation, the relative variability, and others. In this study, we investigated the temporal variability of rainfall

Table 3. Statistics of monthly data for stations used in this study (unit : ㎜)

month \ station	1 Machun	2 Chah wang	3 Jirisan	4 Sugok	5 Seosang	6 Samga	7 Anui	8 Hamyang	9 Unbong	10 Sanchung	11 Wonji	12 Taesu	13 Jungsan	14 Samjung	Mean
1 (mean)	24.7	26.7	50.7	33.4	24.9	21.6	30.1	29.3	49.1	24.5	31.9	30.3	39.9	44.5	33.0
(var.)	760.6	1108.7	6834.8	1449.5	919.7	878.2	1096.8	782.4	9814.4	1422.7	1721.5	1837.1	3501.4	3221.8	
(cov.)	1.12	1.25	1.63	1.14	1.22	1.37	1.10	0.96	2.02	1.54	1.30	1.42	1.48	1.28	1.34
2	38.4	38.5	59.1	51.8	39.2	37.5	50.7	44.7	38.1	39.9	37.1	41.5	58.2	59.4	45.2
	1000.6	1182.6	1836.5	1760.5	1020.3	1323.2	4024.3	1281.9	806.6	1751.1	1982.8	2104.9	3830.6	5624.4	
	0.82	0.89	0.73	0.81	0.82	0.97	1.25	0.80	0.75	1.05	1.20	1.11	1.06	1.26	0.97
3	63.1	56.3	101.0	81.5	57.6	68.0	54.5	54.1	60.8	71.7	79.9	75.7	66.5	76.9	70.6
	2131.1	1695.3	11038.8	2828.9	1799.3	2515.9	2474.8	2202.7	1342.2	776.0	2500.3	1389.7	2066.5	2630.4	
	0.73	0.73	1.04	0.65	0.74	0.74	0.77	0.73	0.60	0.39	0.63	0.49	0.68	0.67	0.69
4	111.3	98.7	155.9	147.8	90.6	111.3	92.9	100.6	101.5	92.1	115.5	130.9	126.3	130.8	114.7
	3929.8	2324.0	6232.2	5837.4	1943.4	2667.2	2839.9	2738.2	2663.4	1536.3	3598.9	4073.2	5875.6	3101.1	
	0.56	0.49	0.51	0.50	0.49	0.46	0.57	0.52	0.51	0.43	0.52	0.49	0.61	0.43	0.51
5	97.8	91.6	116.2	117.3	87.9	93.6	99.7	92.9	92.8	68.4	97.1	103.9	175.4	113.2	103.4
	2856.5	2484.3	4273.4	5246.2	2517.6	3046.1	4647.9	3105.7	2539.5	1191.0	3243.9	4100.9	8886.6	3535.1	
	0.55	0.54	0.56	0.62	0.57	0.59	0.68	0.60	0.55	0.51	0.59	0.62	0.54	0.53	0.57
6	117.6	163.3	208.1	204.4	157.1	174.5	165.9	170.2	176.4	187.4	203.2	205.9	305.8	302.9	200.2
	13735.6	7469.1	17754.5	13956.0	8110.9	11712.5	10071.7	10264.7	11330.1	11683.1	14988.3	14031.8	21902.8	36002.9	
	0.66	0.53	0.64	0.58	0.57	0.65	0.61	0.61	0.60	0.58	0.60	0.58	0.48	0.63	0.59
7	330.9	281.1	345.0	303.9	289.6	262.9	286.4	305.5	322.6	323.3	355.3	374.5	462.9	420.3	333.2
	35087.0	21149.9	46318.7	31670.2	19349.8	21964.4	25033.0	19573.5	19624.4	22755.7	22734.0	30243.9	64340.7	50459.4	
	0.57	0.52	0.62	0.59	0.48	0.56	0.55	0.46	0.43	0.47	0.42	0.46	0.55	0.53	0.52
8	318.8	282.7	361.9	299.6	251.2	263.3	238.9	254.4	249.8	336.4	320.5	345.7	427.9	365.5	308.3
	21553.0	30790.5	41038.4	25175.7	15517.1	17803.5	11714.3	16069.2	18141.6	34886.0	22326.2	24389.9	53222.7	70888.7	
	0.46	0.62	0.56	0.53	0.50	0.51	0.45	0.50	0.54	0.56	0.47	0.45	0.54	0.73	0.53
9	152.7	148.7	168.4	182.1	119.1	145.3	128.4	141.1	140.9	218.7	200.9	222.8	258.2	186.9	172.4
	12531.4	11111.3	19477.8	20315.7	8203.6	9245.4	6958.5	9695.3	11727.4	15326.1	12841.2	15591.5	25090.1	11052.7	
	0.73	0.71	0.83	0.78	0.76	0.66	0.65	0.70	0.77	0.57	0.56	0.56	0.61	0.56	0.680
10	58.4	51.1	59.1	53.8	61.0	49.9	49.6	50.6	62.6	51.0	37.4	40.2	57.3	38.6	50.8
	2766.7	2067.5	2667.7	2456.6	2255.1	2227.2	1723.7	1838.5	2009.5	1975.1	1387.9	2119.9	3779.5	2499.1	
	0.90	0.89	0.87	0.92	0.78	0.95	0.84	0.85	0.72	1.80	0.99	1.15	1.07	1.30	0.95
11	48.1	38.4	44.8	44.3	49.1	37.2	44.8	43.9	55.9	37.1	42.7	46.9	44.5	34.1	43.7
	1767.8	1108.9	1929.6	1847.9	1389.5	1249.5	984.7	1250.1	1150.4	1017.5	1522.2	1986.4	1122.2	683.7	
	0.87	0.87	0.987	0.97	0.76	0.95	0.70	0.81	0.61	0.86	0.91	0.95	0.75	0.77	0.84
12	27.1	22.8	33.4	19.7	25.6	13.4	21.1	23.0	33.4	17.4	16.1	17.3	24.4	24.8	22.8
	382.8	736.7	801.5	361.4	402.1	170.8	260.8	291.2	523.1	452.7	317.4	384.5	490.1	486.2	
	0.72	1.19	0.85	0.97	0.78	0.98	0.77	0.42	0.69	1.22	1.11	1.13	0.91	0.89	0.83
TOTAL	1448.9	1299.9	1703.6	1539.6	1252.9	1278.5	1273.0	1320.3	1383.9	1457.9	1537.6	1635.6	2047.3	1797.9	1498.4

distribution with elevation and position of station, with use of the coefficient of variation, C_V, defined as $C_V=(S/P)\times 100$, P being the average rainfall and S the standard deviation. The coefficient of variation is found to be greatest at places at low latitudes with arid climates (Edward, 1992).

1. General Characteristics

In Korea, there is very large variation of precipitation annually and seasonally, and the precipitation has two distinctive periods. During the rainy period the causes of rainfall are the formation of a trough of low atmospheric pressure, the simultaneous existence of a southwesterly wind and a cold air current, orographic effect, a long dated stagnation of a trough of low atmospheric pressure, and typhoons. In the southern part of Korea, half of annual precipitation is caused by low pressure systems, and 30 % of annual precipitation is caused by weather front. However, in the summer period, most rainfall is caused by weather fronts and typhoons.

The mean annual precipitation of fourteen rain gauge stations in the Nam River dam basin is widely distributed from 1252.9mm to 2047.3mm with a mean value of 1498.4mm. Thus, the study area can be categorized as a considerably high rainfall area. The annual amounts of individual stations are between 83% and 137% of the mean annual rainfall value. Figure 3 shows the distribution of mean monthly precipitation in this area. Table 3 lists the values of the mean monthly precipitation, variance and coefficient of variation for each station. This basin has two distinctive periods: One is the dry period from October to March, and the other is the rainy period from April to september. In addition, the rainfall amount in the rainy period, from June to September, forms more than 70% of the annual precipitation. The standard deviation of mean annual rainfall is about 224.1mm, and the coefficient of variation is about 15%.

Figure 4 shows the distribution of mean monthly coefficient of variation. The low values of the mean monthly coefficient of variation occur during the rainy period, April to September. This means the rainfall amount in the rainy period which is caused by weather fronts and typhoons does not vary widely from year to year. The relation between the mean annual precipitation and the coefficient of variation is shown in Figure 5. Each data point shown in the Figure 5 corresponds to the gauging station record used. The relation can be described by the following formula:

$$Cv(\%)=100\,\frac{S}{P}=10^{0.000146P+1.219},\ R^2=0.679 \quad (1)$$

where S is standard deviation, P is mean annual precipitation in mm, and R^2 is the coefficient of determination. This equation shows that there is greater variability of annual rainfall with increasing mean rainfall amount at a point. According to Jones et al.(1981), the coefficient of variation over the Near East and Northern Africa can be given as

$$Cv(\%)=922.29\,P^{-0.5992},\ R^2=0.856 \quad (2)$$

This equation has opposite meaning as compared with eq.(1). Jones et al.(1981) emphasized that the coefficient of variation of annual and seasonal point rainfall amount is, in general, negatively correlated with the mean annual rainfall in arid area. However this results shows that this relationship may be different according to locality, especially in the temperate, mountainous regions.

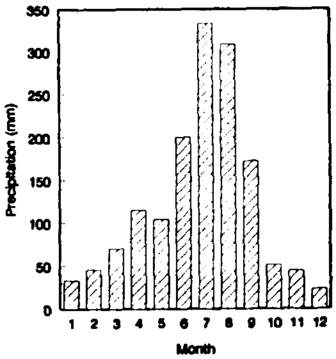

Figure 3. Distribution of mean monthly precipitation

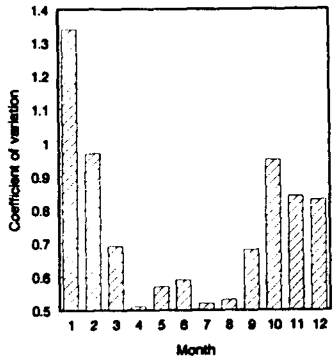

Figure 4. Distribution of mean monthly coefficient of variation

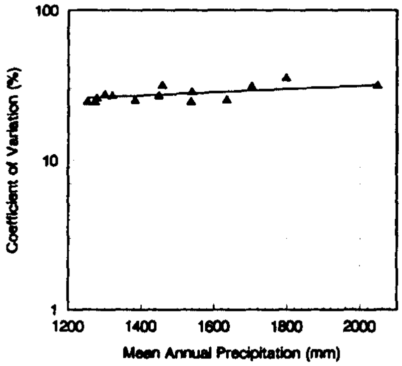

Figure 5. The relation between the mean annual precipitation and the coefficient of variation

2. Effect of Elevation

The relation between elevation and mean annual precipitation on the windward slope for the Nam River dam basin is plotted in Figure 6. The relation between elevation and mean annual precipitation amount based on regression analysis can be expressed as follows:

Mean annual precipitation up to 600m height ; $P(h)=0.699h+1425.9,\ R^2=0.640$ (3)

where P(h) is the precipitation amount in mm and h is the elevation at any point in m. Eqs.(3) imply greater amount of precipitation with increasing elevation at a point. There are many studies on the effect of elevation on annual rainfall(Ballantyne, 1983; Jones et al, 1981; Shumaker et al., 1984; Osborn, 1984). The gradient of increasing rainfall in mm with additional elevation in m has been reported to be 0.1 to 2.4mm/m. depending upon the study area. In this study, the gradient of increasing rainfall with elevation has a seasonal variation, high rate in rainy period, low rate in dry period and 0.495mm/m in mean annual precipitation On the windward slope. This results exhibit similar variation to those reported by Osborn(1984) for arid and high elevation areas in Arizona, U. S., but the rate is higher than the reported values.

The monthly rainfall distribution for three sample stations of different elevations, high, low and medium elevation, is shown in Figure 7. The distribution of monthly rainfall shows a clear distinction between rainy and dry periods. The maximum values of the monthly rainfall amounts occur during July and August. The monthly rainfall amounts during the rainy period vary by the elevation of stations, but such a variation is small during the dry period. Figure 8 shows the monthly coefficient of variation for the same three sampling stations. In his study in the mountainous region of the Reventazon River basin of Costa Rica, Chacon and Fernandez(1985) found that the largest values of the coefficient of variation occurred at high altitudes and the lowest values at middle altitudes. They were large in the December~April period and small in the May~November period. In this study, however, as seen from this Figure 8, there is hardly any regularity in the amount of rainfall during the six-month period from October to March because the coefficient of variation reaches 80% or more during that period regardless of the elevation. However, one can see the regularity in rainfall for the period from April to September with the coefficient of variation of 50-60%. However, no pattern in the variation of the coefficient of variation was detected with the elevation of the raingauging stations through the distribution of the coefficient of variation in the Nam River basin.

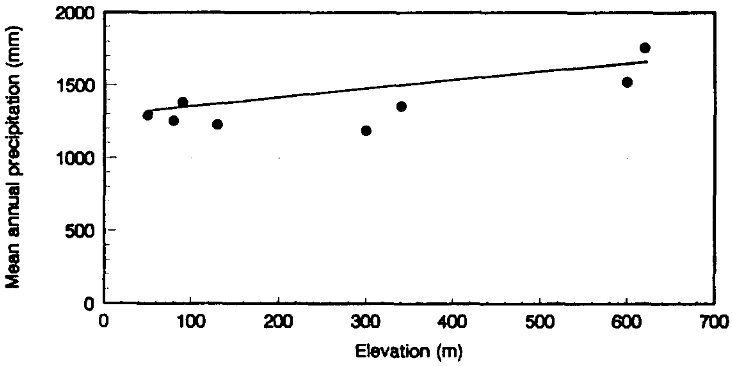

Figure 6. The relation between elevation and mean annual precipitation

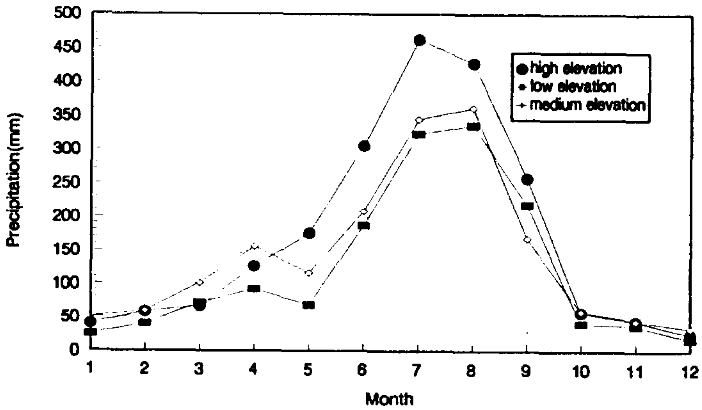

Figure 7. The monthly rainfal distribution for three sample stations

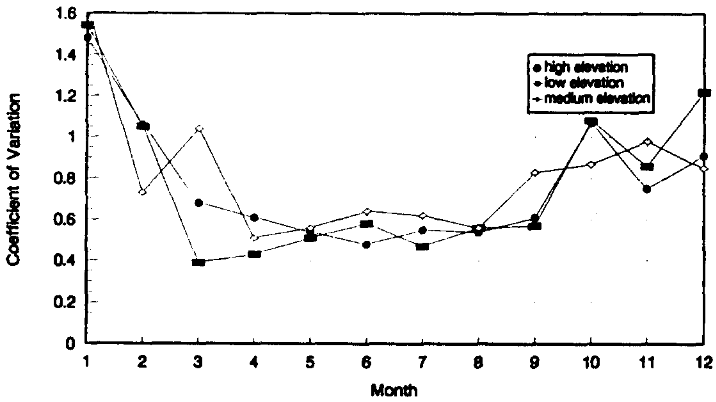

Figure 8. Monthly distribution of coefficient of variation at the different elevations

3. Effect of Position

The monthly rainfall distribution for six representative stations, including Jungsan , Unbong, Jirisan, Chahwang, Sugok and Samga station is shown in Figure 9. The monthly rainfall amounts during the rainy period vary not only with elevation but also with position. For two stations, Jungsan and Unbong, which are located at similar elevations, the average monthly rainfall at the windward sided Jungsan station varied from 180mm to 470mm. On the other hand, the average monthly rainfall of Unbong located on leeward side, varied from 120mm to 360mm. This shows that the average monthly rainfall at Jungsan is 1.4～1.7 times as much as that of Unbong. Furthermore, in the case of Jirisan and Chahwang which are located at medium elevation, and in case of Sugok and Samga which are located at low elevation, rainfall at windward sided Jirisan and Sugok are 1.2 times as much as that of leeward sided Chahwang and Samga. These results shows that the variability of rainfall with the position of rain gauge is rather large. For three stations on leeward side, no difference in the amount of rainfall with the elevation is detected. This means that the amount of rainfall at stations on windward side is high by large scale cooling of air masses due to increase of elevation during the rainy period, from April to September, when cyclones pass frequently. For the stations on leeward side, the amount of rainfall recorded is low regardless of the elevation value. Figure 10 shows the monthly distribution of the coefficient of variation for the representative stations. There does not appear to be any regularity in the amount of rainfall during the six-month period from October to March because the coefficient of variation reaches 60% or more during that period regardless of the elevation and the position. However, one can see the regularity in rainfall for the period from April to September with the coefficient of variation of 50～60%. However, no pattern in the change of the coefficient of variation was detected with the elevation and position of the raingauging stations through the distribution of the coefficient of variation in the Nam River dam basin.

Ⅴ. Spatial Rainfall distribution

Spatial rainfall variability chiefly depends on

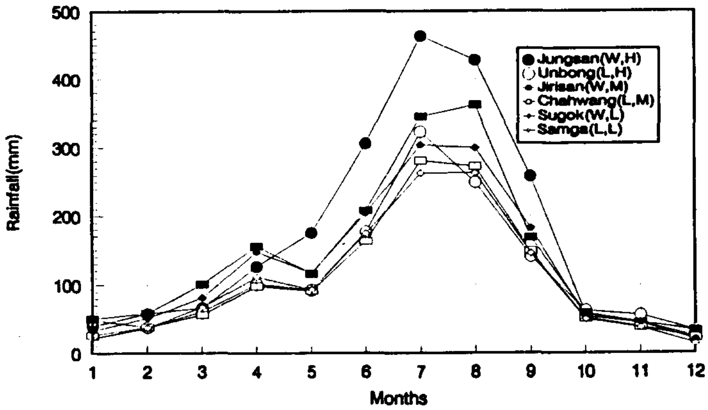

Figure 9. Monthly rainfall distribution at six representative stations

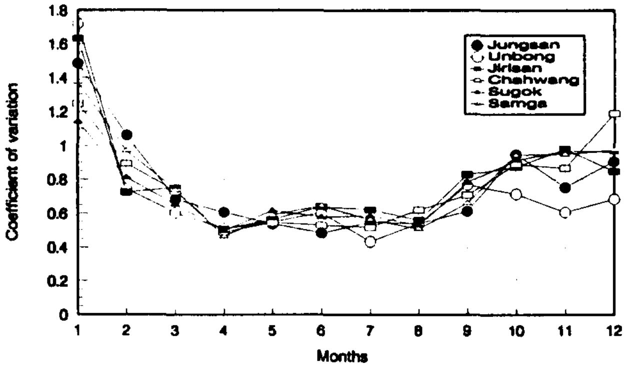

Figure 10. Monthly distribution of the coefficient of variation

the latitude, distance from the ocean, elevation and shape of the terrain. Increased orographic uplift on windward slopes enhances the likelihood of clouds dense enough for rain to form. The increase appears to be greater at low latitudes, presumably because the warmer air can hold more moisture. Also increase with elevation is more consistently expressed as a percentage per 100m than as an absolute increase (Edward, 1992). The spatial rainfall variability was investigated using the correlation coefficient, r, defined as:

$$\gamma = \frac{n\Sigma(X_iY_i) + \Sigma X_i \Sigma Y_i}{\sqrt{[n\Sigma X_i^{s} - (\Sigma X_i)^2]\ [n\Sigma Y_i^{s} - (\Sigma Y_i)^2]}} \qquad (4)$$

where n is the number of pairs of rainfall values for stations X and Y. Guidelines for interpretation based on the correlation coefficient are as follows: no correlation if $r=0$, weak correlation if $0<r<0.5$, medium correlation if $0.5<r<0.8$, strong correlation if $0.8<r<1.0$, perfect correlation if $r=1$ (Anderson and Sclove, 1978).

1. General Characteristics

The pattern of spatial rainfall distribution in Korea depends chiefly on the shape of the terrain. The study area has very complicated topography and is located close to the coast. The annual amount of precipitation is larger than other regions in Korea. The prevailing wind directions in this area are southerly, westerly, and southwesterly. Table 4 lists the correlation coefficient of annual precipitation between the sta-

Table 4. The correlation coefficient of annual precipitation between two stations

Station no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2	0.8389													
3	0.7702	0.7444												
4	0.8680	0.8654	0.8193											
5	0.7993	0.7619	0.6909	0.7999										
6	0.7737	0.8054	0.7937	0.8427	0.6802						-Sym.-			
7	0.7767	0.7928	0.6597	0.8131	0.8638	0.7915								
8	0.9163	0.8261	0.78325	0.8654	0.8983	0.7439	0.8443							
9	0.8627	0.7687	0.7242	0.8130	0.8908	0.7215	0.7974	0.9151						
10	0.8233	0.8630	0.8662	0.9107	0.9454	0.8952	0.9178	0.8791	0.8603					
11	0.7858	0.8659	0.8152	0.9072	0.8418	0.9415	0.8516	0.8168	0.8059	0.9167				
12	0.8099	0.8711	0.8343	0.9277	0.8376	0.9454	0.8011	0.8123	0.8332	0.8855	0.9824			
13	0.7663	0.9469	0.7666	0.9069	0.8458	0.8319	0.7375	0.7376	0.8240	0.7972	0.8398	0.8793		
14	0.7815	0.7866	0.7589	0.7725	0.8306	0.8823	0.8427	0.7730	0.7716	0.8814	0.8562	0.8371	0.7059	
Mean	0.8617	0.8252	0.7718	0.8624	0.8220	0.8191	0.8069	0.8351	0.8145	0.8801	0.8629	0.8659	0.8143	0.8062

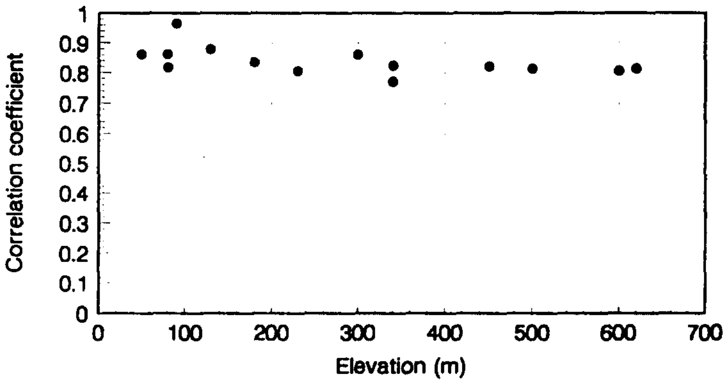

Figure 11. Relation between elevation and the average correlation coefficient of stations

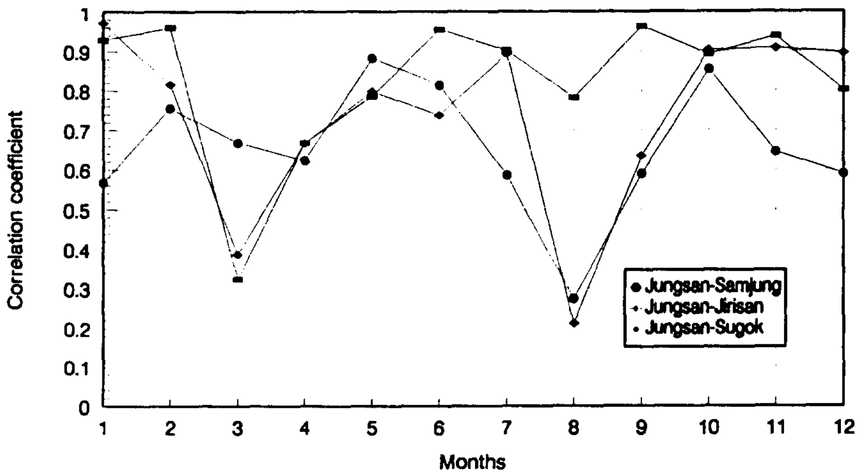

Figure 12. Monthly distribution of the correlation coefficient for the Jungsan station and three representative stations

tions. The correlation coefficient, r, of annual precipitation in this basin has high values of more than 0.77, with the average value of 0.8320. The value recorded at windward side and low elevation stations is above average.

2. Effect of Elevation

The relation between elevation and the average correlation coefficient of stations is shown in Figure 11. The correlation coefficient marginally vary with elevation of stations. In Figure 12, the monthly distribution of the correlation coefficient for the Jungsan station, located in the high elevation area and three representative stations, is shown. Except for a high value at low elevation there does not appear to be any regularity in the temporal pattern of the correlation coefficient with the raingauging station elevation. Only in the months of March and August, the correlation coefficient is extremely low at most of the stations. This phenomenon is supposedly caused by the irregular distribution of rainfall due to the Baiu front and typhoons. These results are similar to those of Chacon and Fernandez(1985).

3. Effect of Position

The monthly correlation coefficient of three pairs of stations with similar elevation and different positions is shown in Figure 13. It is seen that a high value of the correlation coefficient was recorded for two low-elevation stations and a low value for two high-elevation stations without regard to their position. This means that at higher elevation, there is more effect of position on rainfall distribution. Referring to Figure 5, the values of the coefficient of variation for mean annual precipitation show a relatively uniform distribution with a value of 0.2~0.3. In the case of the stations on the windward side, the coefficient of variation appeared to change with the elevation; but for the stations on the leeward side, there was no uniform pattern of change.

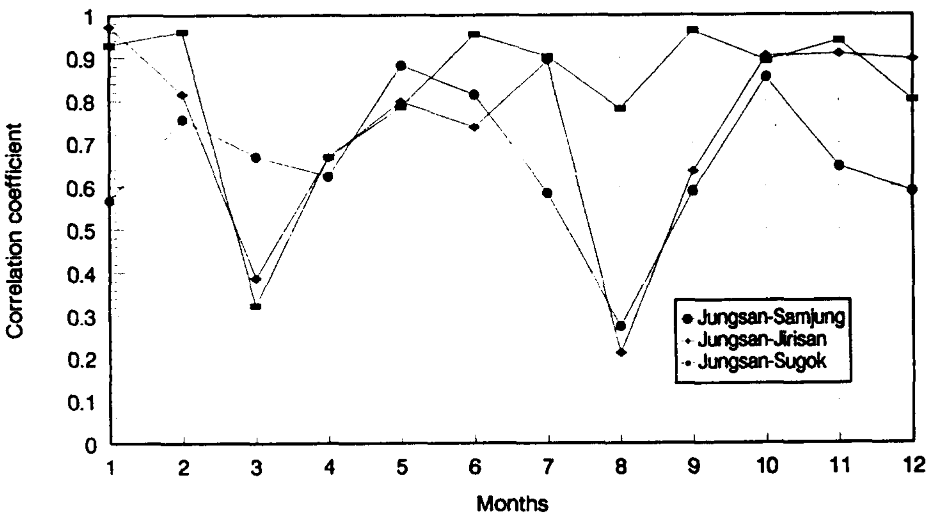

Figure 13. The monthly distribution of the correlation coefficient for the Jungsan station and three representative stations

4. Effect of Distance and Direction

The correlation between rainfall value measured at two places depends on the distance between them, the kinds of terrain, type of rainfall, and whether one considers daily, monthly or annual precipitation(Edward, 1992). The correlation is highest for places which are close to each other. In this study, author considered the distance along the predominant wind directions as well as distance between stations. The monthly correlation coefficient for Wonji, Taesu, Sanchung, and Chahwang stations toward Sugok station is shown in Figure 14. This correlation coefficient is for stations from south to north. From the figure, the correlation coefficients are relatively uniform and are considerably strong with values being higher than 0.6. In addition author represented the correlation coefficient of stations from east to west in Figure 15 and from southwest to northeast in Figure 16. In these figures, variations of the correlation coefficient are different from the previous case with values of 0.3~1.0. The values are irregular but one can infer that the correlation coefficients of rainfall for south-north direction are larger than those of rainfall for other directions. The similarity of rainfall pattern and intensity in the Nam River dam basin is predominant in south-north direction. The reason is assume that the prevailed wind direction is southerly wind in this area. One can assume that even though the magnitude of change in monthly rainfall in the Nam River dam basin is large, the change in the mean annual rainfall is small so that there will be no difficulty in maintenance of water resources. Because the change in the amount of mean annual rainfall and the amount of monthly rainfall is high in the area of high elevation on windward side than in the area of low elevation on windward side, this point should be considered in calculating the mean areal rainfall, and in design of rain gage network.

The correlation coefficient for yearly rainfall with distance along east to west, south to north, and southwest to northwest directions is depicted in Figure 17. For the amount of annual rainfall, the correlation coefficient of east to west direction is relatively high. In the south to north and southeast to northwest directions, the correlations are similar. However, in the east to west direction, the slope of change in correlation coefficient is quite large with distance, though there is a high value at close distance between two stations. Through these relationships, one can see that the shorter the distance is, the higher the correlation is, and that this correlation lies in the east to west direction and is smaller than the correlation in other directions. This point can be one of the factors which should be used in computing optimal mean areal rainfall when designing the rain gage network in the Nam River dam basin. The expressions for the correlation function with distance by direction using regression analysis are:

$$\begin{aligned}
&\text{Direction S} \rightarrow \text{N} : r(d) = \\
&\quad -0.002325d + 0.806,\ R^2 = 0.863 \\
&\text{Direction SW} \rightarrow \text{NE} : r(d) = \\
&\quad -0.005702d + 0.850,\ R^2 = 0.953 \\
&\text{Direction W} \rightarrow \text{E} : r(d) = \\
&\quad -0.007228d + 1.006,\ R^2 = 0.871
\end{aligned} \tag{5}$$

where d is the distance in km. The result of Huff and Shipp(1969) have similar trend to this results but those of Chacon(1989) are different in magnitude and the decreasing rate of the correlation coefficient. These differences are due to the topographical characteristics.

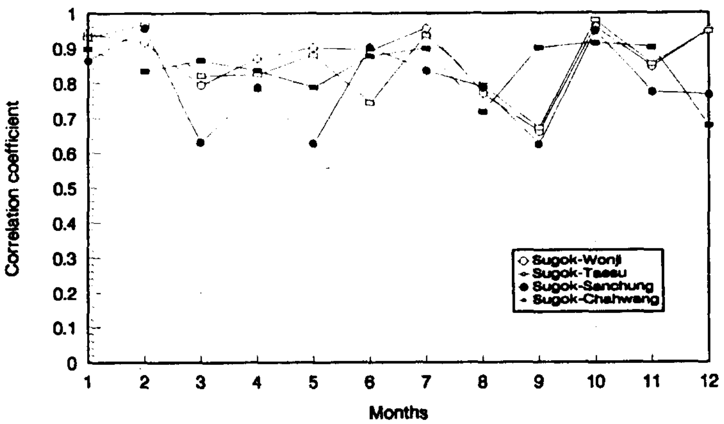

Figure 14. Monthly distribution of the correlation coefficient of stations from south to north

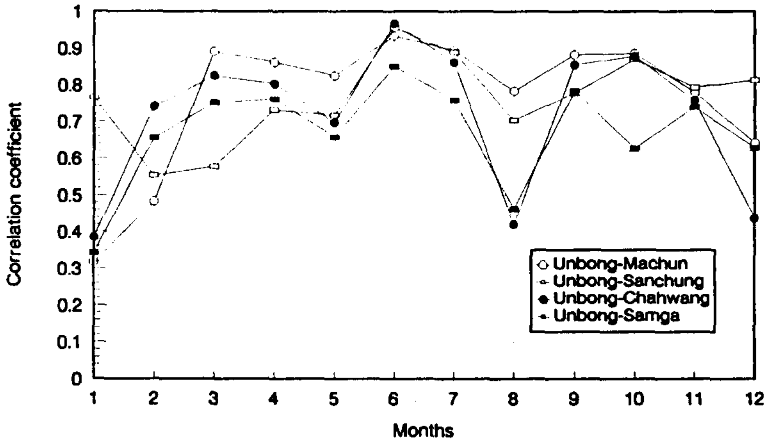

Figure 15. Monthly distribution of the correlation coefficient of stations from east to west

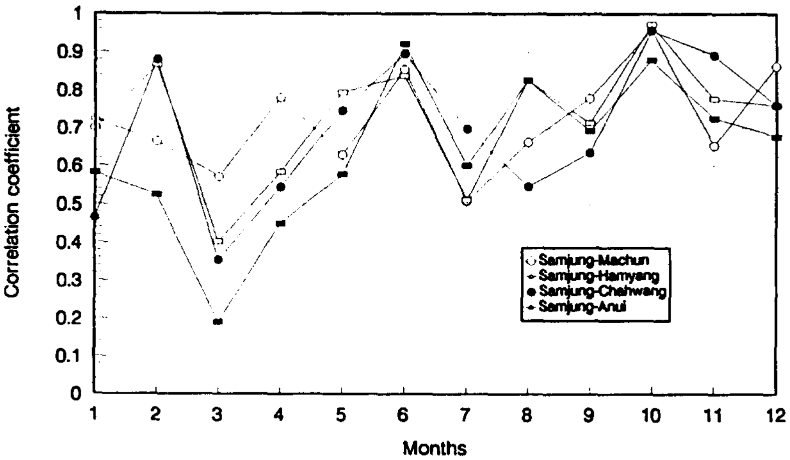

Figure 16. Monthly distribution of the correlation coefficient of stations from southwest to northeast

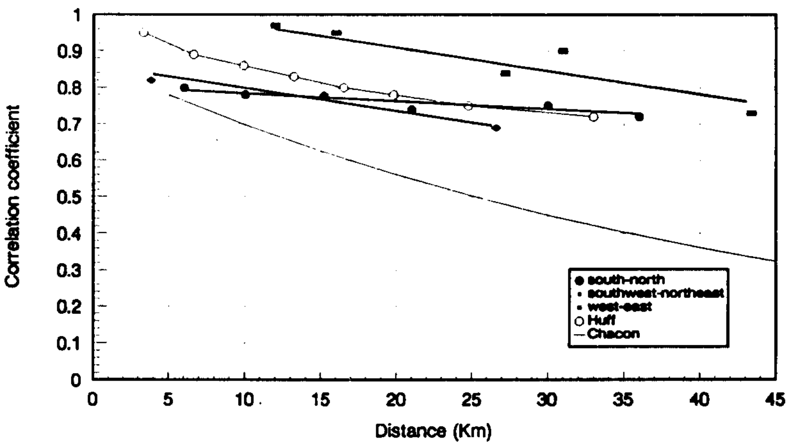

Figure 17. Correlation coefficient for annual precipitation with distance

Ⅵ. Conclusions

The following conclusions can be drawn from this study: (1) There is greater variability of annual rainfall with increasing mean rainfall amount at a point. (2) The gradient of increasing rainfall with elevation had a seasonal variation: high rate in rainy period, low rate in dry period, and 0.699mm/m in annual precipitation on the windward slope. (3) No pattern in the temporal change of the coefficient of variation was detected with elevation and position of the raingauging stations. (4) In the case of stations on the windward side, the coefficient of variation appeared to spatial change with the change in elevation; but for the stations on the leeward side, there was no uniform pattern of change. (5) In the east to west direction, the slope of change in correlation coefficient was quite large with distance, though there was a high value at a close distance between two stations.

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〈접수 : 9월 7일〉