KOREAN STREAMFLOW PATTERNS IN RELATION TO El NIÑO/SOUTHERN OSCILLATION

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Abstract: Streamflow patterns at two gauging stations in Korea, An-Dong dam and Chung-Ju dam, are statistically analyzed in relation to El Niño/Southern Oscillation (ENSO). As a measure of ENSO, the Southern Oscillation Index (SOI) is used on a monthly and seasonal basis. The traditional correlation analysis shows that cross correlations of the SOI with the seasonal streamflow are generally weak. To investigate the relationship between the extreme values of the SOI, which represent the El Niño and La Niña events, and the corresponding streamflow patterns, the composite analysis is employed in this study. The composite analysis demonstrates that when El Niño occurs, seasonal streamflows at An-Dong and Chung-Ju dams during the period from September of the El Niño year to February of the following year appear to be drier than their means.

Key Words: El Niño/Southern Oscillation, streamflow patterns, composite analysis

1. INTRODUCTION

The phenomenon known as El Niño/Southern Oscillation (ENSO) is a complex ocean/atmosphere interaction which causes a cyclic warming and cooling of the sea surface in the eastern Pacific. El Niño corresponds to the warm phase of ENSO while La Niña corresponds to the cold phase of ENSO. The phenomenon has been identified as the single most prominent signal of interannual climate variability. A number of independent efforts have been made to investigate the relationships between ENSO and hydrologic variations. Especially interesting are some statistically significant relationships of ENSO with streamflows in Australia (Simpson et al., 1993), New Zealand (Moss et al., 1994), South America (Hastenrath et al., 1993), the Western United States (Piechota et al., 1997), and elsewhere. In such cases, the ENSO could be used as an indicator for forecasting the long-term streamflow. A reliable streamflow forecast would be invaluable to water resources planners and managers.

In this paper, the teleconnection between ENSO and streamflows in Korea is investigated. Although researches on the potential ENSO impact on precipitation and streamflow in Korea only began in the late 1990's, many climatologists and hydrologists are currently showing interest in this hydrologic issue. The present paper investigates two streamflow gauging stations, An-Dong dam and Chung-Ju dam, associated with the ENSO events, especially using a statistical technique called the composite analysis.

2. DATA

2.1 ENSO Measure

Trenberth (1997) recommended that it should be stated which scientific definition of El Niño/La Niña is being used because a satisfactory quantitative definition has not yet been achieved. This study uses the Southern Oscillation Index (SOI), which is a standard measure of the concurrent differences in sea level atmospheric pressures at Darwin, Australia, and Tahiti (Philander, 1990). The El Niño event corresponds to a low SOI and the La Niña event corresponds to a high SOI. Ropelewski and Jones (1987) define the El Niño (or La Niña) years as the years during which the SOI remained in the lower (or upper) 25% of the distribution for five months or longer. Table 1 lists the El Niño and La Niña years by Ropelewski and Jones, which are used in this study.

2.2 Streamflow Data

This study examines two gauging stations, An-dong dam in the Nak-Dong River basin and Chung-Ju dam in the South Han River basin (Figure 1). The Nak-Dong River basin covers approximately 23,000 km^2 of South Korea and the An-dong multipurpose dam is located approximately 340 km upstream of the river mouth. The South Han River basin is approximately 13,000 km^2 large and the

Table 1. El Niño and La Niña Years by Ropelewski and Jones

El Niño	La Niña
	1956
1957	
1963	
	1964
1965	
1969	1970
	1971
1972	
	1973
	1975
1977	
1982	
1983	1983
1994	
1997	

Chung-Ju multipurpose dam is located approximately 9 km northeast of the city of Chung-Ju.

Monthly streamflow series at An-Dong dam and Chung-Ju dam stations are available since the years of 1954 and 1956, respectively, but 42 year records from 1956 through 1997 are used for both stations. Table 2 shows key statistics of the monthly streamflow data at both stations. A lognormal distribution is fitted to each month of the streamflow data for both stations and appears to be a good distribution model for all months.

Table 3 shows cross-correlation coefficients between the seasonal SOI and the seasonal streamflow data at An-Dong dam. There exists little significant correlation between the two series. This is also true for the other station. However, a cross-correlation coefficient represents only an average linear relationship between two variables. In other words, it may not be a good measure between two variables if there is a nonlinear relationship and/or if a certain range of a variable is more important

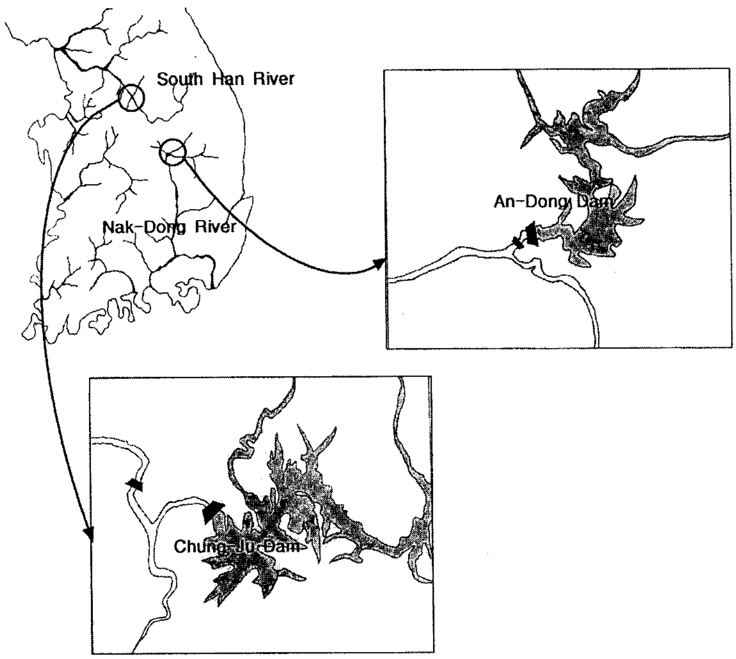


Fig. 1. Location Map of An-Dong Dam and Chung-Ju Dam Gauging Stations in Korea

Table 2. Key Statistics of the Monthly Streamflow Data at An-Dong Dam and Chung-Ju Dam

Unit: m^3/sec

Month	Chung-Ju Dam		An-Dong Dam	
	Average	Standard Deviation	Average	Standard Deviation
1	30.6	13.9	4.7	4.2
2	34.9	31.4	7.4	8.3
3	89.1	72.9	14.4	10.2
4	198.0	139.8	33.2	32.4
5	126.6	76.9	26.0	18.8
6	136.3	140.0	33.2	35.8
7	507.5	274.2	78.6	42.8
8	347.7	215.3	62.3	43.2
9	290.9	251.1	50.1	37.4
10	90.5	70.3	13.4	12.4
11	64.3	36.2	9.8	10.5
12	45.2	22.6	6.1	6.6

than the rest. This study attempts to investigate the second case: For the ENSO impact studies, extreme values of the SOI, which represents the El Niño and La Niña events, should be considered more important. For this purpose, an alternative approach called the composite analysis is proposed, which can analyze the relationship between the extreme values of the SOI and the corresponding streamflow, and is described in

Table 3. Cross-correlation Coefficients Between the Seasonal SOI and Seasonal Streamflow Data at An-Dong Dam

Winter	Lag	0	1	2	3
	CCF	-0.070	-0.030	0.037	-0.070
Spring	Lag	0	1	2	3
	CCF	0.176	-0.12	0.164	0.152
Summer	Lag	0	1	2	3
	CCF	-0.110	0.329	0.159	0.203
Fall	Lag	0	1	2	3
	CCF	0.262	0.113	0.072	0.158

the following section.

3. COMPOSITE ANALYSIS

The first step in the composite analysis is to transform monthly streamflows at each station into the corresponding percentiles based on the log-normal distribution for each month. In other words, a streamflow from an original time series (q_{mn}) is transformed into $x_{mn} = \ln(q_{mn})$, and x_{mn} is standardized using

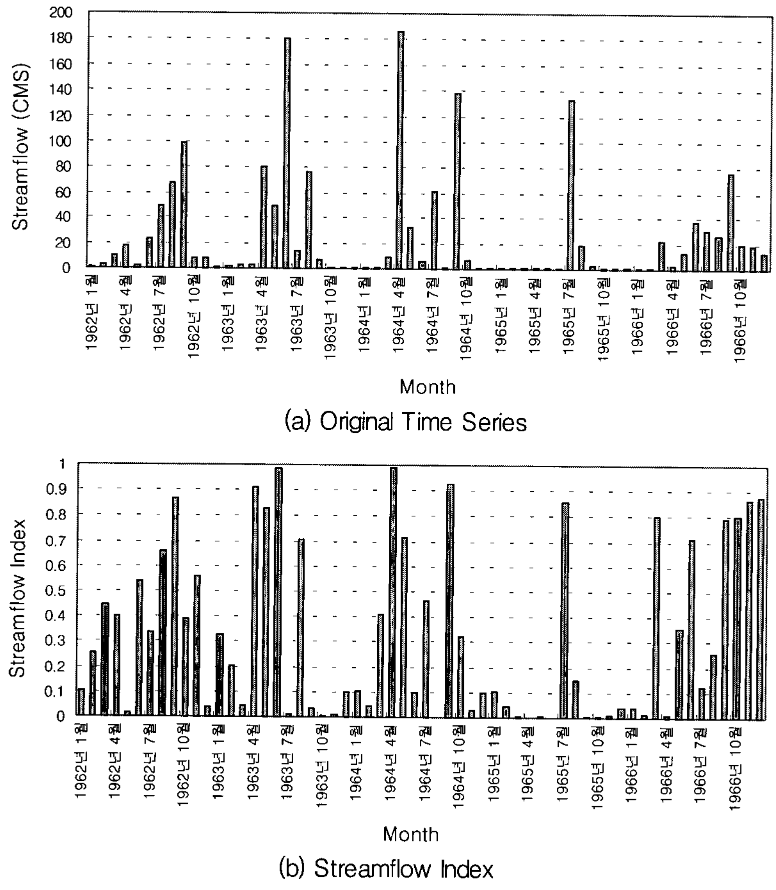
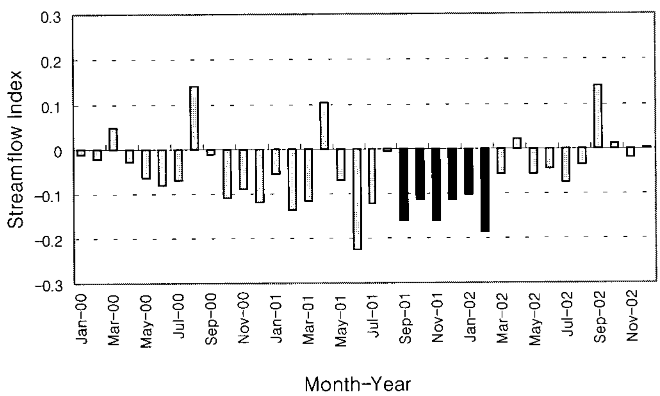


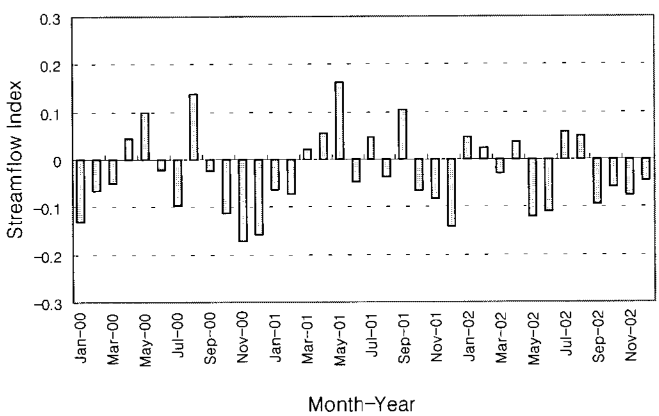
Fig. 2. An Example of Streamflow Index Series for An-Dong Dam Station

$z_{mn} = (x_{mn} - \mu_m)/\sigma_m$ for each month m and for each year n. The standardized variable follows a standard normal cumulative probability function with its percentile, $F(z_{mn})$. The time series of these monthly percentiles is called the streamflow index series. Figure 2 shows a typical result of the transformation of monthly streamflows to streamflow indices for a 5 year period taken from 42 years at the An-Dong dam.

The next step is to create the El Niño (or La Niña) composite streamflow index from the streamflow index. For this purpose, we refer to the El Niño year as year-1 and also refer to the preceding and the following years as year-0 and year-2, respectively. The streamflow of the El Niño year indices are then extracted for the 36-month period starting with January of year-0. Since 10 El Niño events occurred during the study period as shown in Table 1, 10 sets of the 36-month streamflow indices are chosen. For each month of these 36 months, 10 streamflow indices are averaged to create an El Niño composite streamflow index for the month. On the other hand, since 7 La Niña events occurred during the study period, 7 streamflow indices are averaged to create the La Niña composite



(a) for El Nino



(b) for La Nina

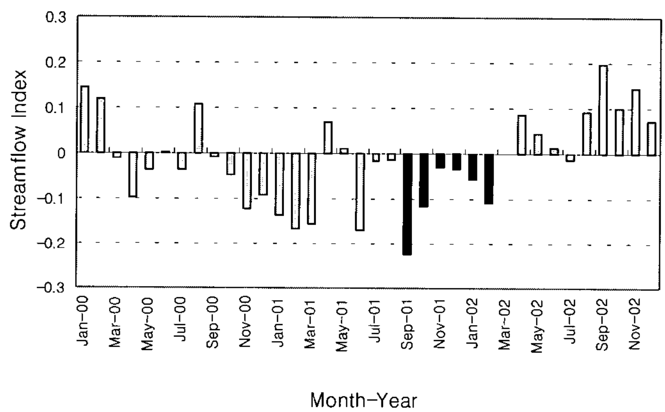
Fig. 3. ENSO Composite Streamflow Indices for An-Dong Dam

streamflow index.

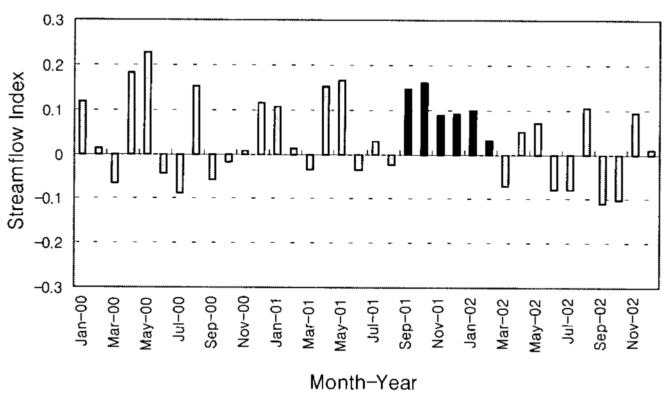
Figures 3 and 4 present the El Niño and La Niña composite streamflow indices for An-Dong dam and Chung-Ju dam, respectively. From Figure 3(a), it is obvious that most of the streamflow indices are below zero, which represents the 50% percentile, i.e. the median (=mean for the normal distribution), when El Niño occurs. Therefore, there may be a possible relationship between El Niño and low streamflows at An-dong dam, especially for the period from September of an El Niño year to February of the following year. On the other hand, Figure 3(b) does not show any consistent patterns. Figure 4(a) shows the similar pattern as in Figure 3(a), thus there also may be a possible relationship between El Niño and low streamflows at Chung-Ju dam, especially for the period from September of an El Niño year to February of the following year. Figure 4(b) presents opposite results: high flows are dominant when La Niña occurs, especially for the period from September of an El Niño year through February of the following year.

4. HYPOTHESIS TEST

The final step is to investigate the statistical



(a) for El Nino



(b) for La Nina

Fig. 4. ENSO Composite Streamflow Indices for Chung-Ju Dam

significance for the potential ENSO-streamflow relationships explored in the composite analysis. In this study, the following three periods that show low streamflow tendencies when El Niño occurs (Figure 3(a) and 4(a)) are tested: (1) Fall (from September of an El Niño year through February of the following year), (2) Winter (from September through November of an El Niño year) and (3) Fall + Winter (from December of an El Niño year through February of the following year). The time series of these seasonal streamflow indices are illustrated in Figures 5 and 6 and the El Niño years are shaded black.

The significance level for the El Niño-streamflow relationship is then estimated using the hypergeometric distribution. For each of the above period, the following two cases are tested:

Case I: the number of negative departures from the mean for the El Niño-low streamflow relationship, and

Case II: the number of El Niño year departures of the streamflow index below the 10th percentile for the El Niño-low streamflow relationships.

A success in the hypergeometric distribution is defined as the occurrence of a signal season which is drier than the given threshold, which are the mean for Case I and the 10th percentile for Case II. Table 4 reports the results for both cases, where Ph is the cumulative probability of the hypergeometric distribution, m is the number of El Niño year streamflow indices exceeding the threshold, n is the number of El Niño years, and N is the total number of years. As for the An-Dong dam, Case II always shows significance levels less than 0.05, which means the relationships between El Niño and the driest 10% of the

Table 4. Probabilistic Assessment of the Statistical Significance of Seasonal Streamflow Associated with El Niño

(a) Fall

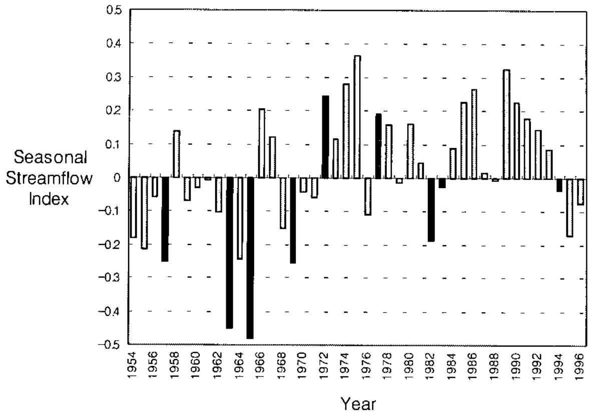
Site	Case	N	k	n	m	Ph
An-Dong	I	43	20	9	5	0.4147
	II	43	4	9	3	0.0441
Chung-Ju	I	41	20	9	6	0.2305
	II	41	4	9	2	0.2168

(b) Winter

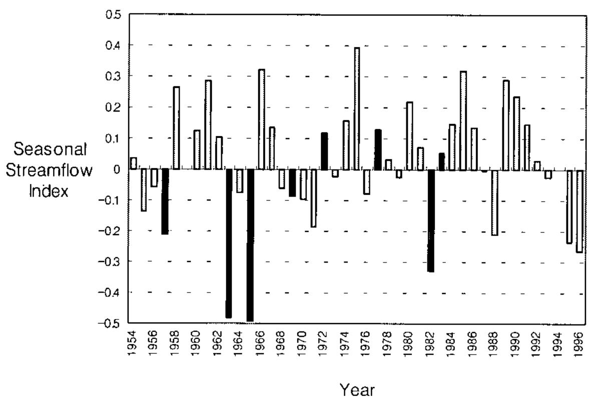
Site	Case	N	k	n	m	Ph
An-Dong	I	43	19	9	7	0.0448
	II	43	4	9	3	0.0441
Chung-Ju	I	41	20	9	6	0.2305
	II	41	4	9	1	0.6030

(c) Fall and Winter

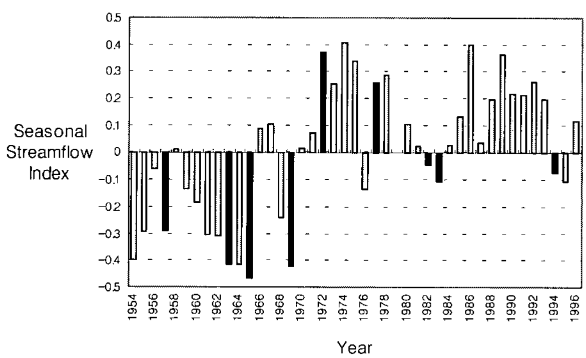
Site	Case	N	k	n	m	Ph
An-Dong	I	43	23	9	7	0.1292
	II	43	4	9	4	0.0064
Chung-Ju	I	41	22	9	7	0.1314
	II	41	4	9	1	0.6030



(a) for El Nino, for period from September to February



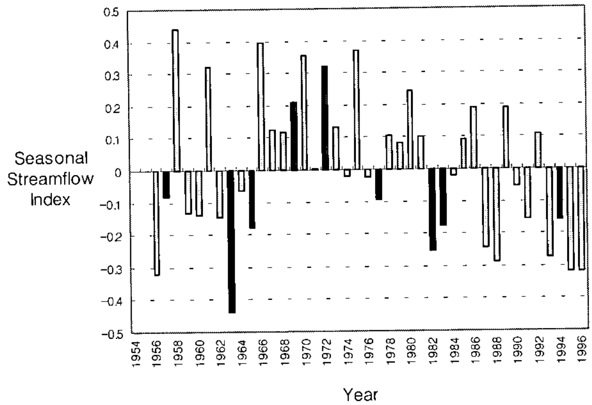
(b) for El Nino, for period from September to November



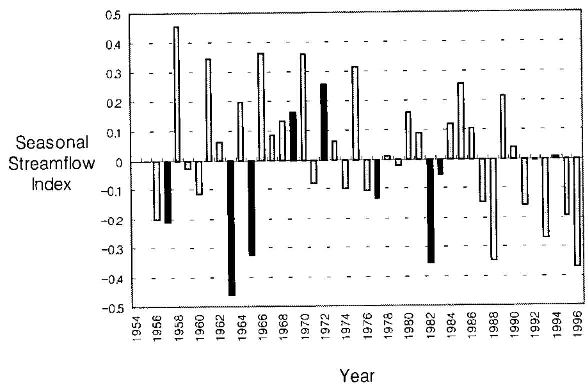
(c) for El Nino , for period from December to February

Fig. 5. Seasonal Streamflow Indices for An-Dong Dam

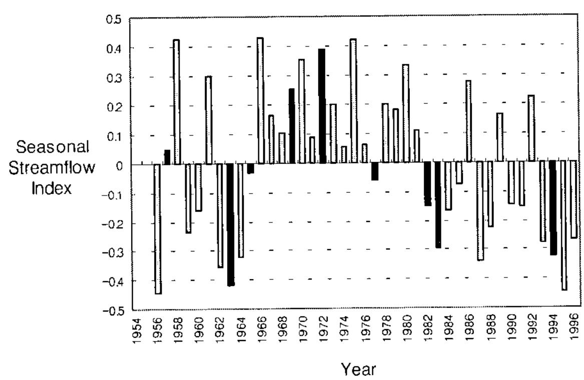
flows for those periods are statistically significant. Case I shows the significance levels less than 0.05 only for the case of winter and the An-Dong dam. As for the Chung-Ju dam, all Ph's are greater than 0.1 but the significance levels for Case I are



(a) for El Nino, for period from September to February



(b) for El Nino, for period from September to November



(c) for El Nino, for period from December to February

Fig. 6. Seasonal Streamflow Indices for Chung-Ju Dam

mildly strong, which confirms a positive relationship between El Niño and low streamflows.

5. CONCLUSIONS

The composite analysis used in this study demonstrated the existence of statistically significant relationships between ENSO and streamflows, which may not be caught by cross correlation coefficients. When El Niño occurs, 3-month and 6-month seasonal streamflows at An-Dong and Chung-Ju dams during the period from September of the El Niño year to February of the following year appear to be drier than their means.

Since the records used in this study are not sufficiently long, the results from this study should be updated when more new data are available. Furthermore, future research should focus on how the current results can be used for improving more reliable long-term streamflow forecasts as well as better operating policies for water resource systems in Korea.

ACKNOWLEDGEMENTS

This research was financially supported by a research fund from Seoul National University. This support is gratefully acknowledged.

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(Received September 7, 1999; accepted February 23, 2000.)