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Factor Analyses for Water Quality Indicators of Streams, Ground Water, and Reservoir in Agricultural Small Catchments of the Han River Basin

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ABSTRACT : The principal indicators contributing to water qualities was screened by factor analyses, based on the monitored chemical parameters of water quality for various water resources from 1995 to 1999 in the small agricultural catchments of the Han River Basin. Water samples of streams, groundwaters, and reservoirs were taken four times a year from upper (Daegwanryong), middle (Dunnae and Chunchon) and lower (Guri) reaches of Han River Basin. In these areas, the respective type of farming practiced was alpine agriculture and livestocks raising, typical upland and paddy cultivation, and intensive cropping in the plastic film house. Water quality was monitored for twenty-one water quality parameters, including pH, EC, SS, T-N, T-P, COD, cations, anions, and heavy metals. pH, EC and COD of the stream waters were suitable for the Korea irrigation water quality guidelines. However, T-N and T-P concentrations of water samples in four catchments far exceeded the irrigation water guideline. Concentrations of cations and heavy metals in Wangsuk stream in Guri area were higher than those in streams in other areas. Factor analysis revealed that significant correlation was observed for 81 pairs out of 231 water quality indicators of stream water among the 21 x 21 cross correlation matrix of stream water quality indicators. The first factor accounted for 27.01% of the total variation in stream water quality indicators, and high positive factor loadings were shown on EC, K, Na, NH_4^+-N, PO_4^{3-}, SO_4^{2-}, and COD. Fifty-three water quality indicator pairs were significant out of 190 ground water quality parameters. The first factor accounted for 28.54% of the total variation in ground water quality indicators, and high loadings were revealed on EC, Ca, Mg, K, Na, NH_4^+-N, and SO_4. Twenty-nine pairs of reservoir water quality indicators were significant out of 66 pairs. The first factor accounted for 37.06% of the total variation in reservoir water quality indicators, and high loadings were shown on EC, Mg, K, Na, SS, T-P, Cl, and COD. These results demonstrate that EC was the first factor contributing to water quality.

Key words : Water quality, Han River basin, Stream water, Ground water, Factor analysis.

INTRODUCTION

In Korea, assessment of water quality indicators in the agricultural watershed has merited a close attention for the environmentally sound sustainable development in agriculture, due to the pollutant loads both from outside of the agriculture, industrial and urban sectors, and from inside of the agriculture (Jung, et al., 1997; Sim, 1994). Korean farming system has driven to maximize agricultural production and to increase farmers' income through adoption of high-yielding crop varieties with high input of agrochemicals. The industrialization and urbanization processes, and even farming practices have deteriorated the water quality (Yoo and Jung, 1999). A sharp increase in nitrogen and phosphorous concentration in agricultural water resources since 1990's was reported (ADC, 1999). Concentrations of heavy metals of the surface water in the vicinity of metal mining sites and smelters were significantly higher than those in agricultural areas (Yoo, 1995).

Water quality monitoring on the major rivers and water resources have been conducted by the Ministry of Environment (MOE, 2000), and monitoring on agricultural water resources by the Agriculture Development Cooperation (ADC, 1999). However, monitoring and evaluation of water quality in the small catchments were limited. Recently, many researchers have initiated the water quality monitoring on the steam and ground water in the small catchments for agricultural water resources (Chung et al., 1998; Han et al., 1997; Im et al., 1999; Jung et al., 1998; Kim et al, 1999; Lee et al., 1993, 1998; Lee et al., 1999a; Lee et al., 1997, Lee et al., 1999a).

Objective of this research was to screen the principal indicators contributing to water qualities by employing the factor analyses, based on the monitored chemical parameters of water quality for various water resources from 1995 to 1999 in the small agricultural catchments of the Han River Basin. Water samples of streams, groundwaters, and reservoirs were taken four times a year from upper (Daegwanryong), middle (Dunnae and Chunchon) and lower (Guri) reaches of Han River Basin, where different types of agricultural practices have been performed: 1) alpine agriculture and livestocks in Daegwanryoung area, 2) typical upland and paddy farming in Dunnae and Chunchon areas, and 3) intensive farming including the plastic film houses in Guri area.

MATERIALS AND METHODS

Water Samples

Water samples were taken four times (April, June, August, and October) each year from 1995 to 1999 from the agricultural areas having different agricultural practices in the small catchments of Han River Basin. Surface water samples were collected from the Daegwanryoung and Dunnae, upper reach of the Han River Basin, Chunchon, middle reach, and Guri, lower reach. The detailed sampling location and number were described elsewhere (Jung et al., 1998).

Water Sample Analysis

Water quality measurements were performed following MOE method (1991). Both pH and EC were measured in the field: pH was measured by a glass electrode, and EC by a conductivity meter. T-N were analyzed by the Kjeldahl distillation method. T-P was measured by $SnCl_2$ reduction method after HNO_3 digestion. NH_4^+-N was determined by indophenol blue methods, and NO_3^--N by Brucine methods. Heavy metals, such as Cd, Cu, Cr, Pb, Fe, Mn and Zn, were analyzed by AAS. Anions such as PO_4^{3-}, Cl^-, NO_3^- and SO_4^{2-} were determined using ion chromatograph. TSS were determined by filtration method, and COD by alkali $KMnO_4$ method.

Factor Analysis

Factor analysis was performed to group water quality indicators into quality factors based on their correlation structure using PROC FACTOR, SAS system, following the method of Bradja et al. (1999). Water quality indicators had different measurement units, so that analysis was performed on the correlation matrix to eliminate this effect in the determination of factor loadings. Principal component analysis was used for the factor extraction. Number of factors with eigenvalues greater than one were subjected to an orthogonal rotation by the varimax rotation which redistributes the variance of significant factors to maximize the relationship between the interdependent variables.

RESULTS AND DISCUSSION

pH, Electrical Conductivity (EC), Suspended Solid (SS), and COD

Table 1 shows pH, EC, and COD values averaged over 5 years. pH of the small catchments of Han River Basin ranged from 6.38 to 8.18. pH of ground water in Guri area showed a lower pH ranging from 6.04 to 6.70 than that of surface water. Except for several sampling sites, most of pHs were in pH 6.0 - 8.5, which were in the criteria for irrigation purpose. pHs measured in April and August were relatively higher than those in June and October.

Averaged EC values in Chunchon, Daegwanryung, and Dunnae area were in the range of good quality as an irrigation water (Jung et al., 1997). Chemical oxygen demand (COD) is the indicator to evaluate pollution level by measuring oxygen amount consumed as organic matter is oxidized, and COD limitation level for irrigation water in our country is 8 $mg \cdot L^{-1}$. Averaged COD values at catchments in Han River basin were lower than 8 $mg \cdot L^{-1}$. COD values varied with sampling locations. Firstly, the COD values in the upper reaches of Soyang river in Chunchon, Wangsuk stream in Guri, and Daegwanryoung and Dunnae area were lower than middle reaches. Secondly, in the middle reaches, COD increased as runoff water derived from agricultural practices increased. Thirdly, the COD values, at lower reach, appeared to decrease through processes such as self-purification of stream and organic matter sedimentation. The highest COD value of 22.5 $mg \cdot L^{-1}$ was detected at the Gonggi tributary in Chunchon in June 1996 (detailed data not shown). This tributary water passes through the concentrated urban area of the Chunchon City.

Total N, NH_4^+-N and NO_3^--N

Concentrations of Total N, NH_4^+ and NO_3^- of streams in

Table 1. pH, EC, SS and COD of the stream water samples collected from four experimental catchments (yr 1995-1999).

Area	Month	pH	EC($\mu S \cdot cm^{-1}$)	SS($mg \cdot L^{-1}$)	COD($mg \cdot L^{-1}$)
Chunchon	April	7.62 (6.96~8.98)	128.6 (49.6~231.4)	52 (15~78)	2.15 (0.24~3.91)
	June	7.62 (7.06~8.88)	159.3 (59.1~308.0)	56 (27~81)	3.54 (1.03~22.51)
	August	7.81 (6.28~9.98)	121.0 (44.5~265.7)	55 (11~98)	3.19 (0.16~5.49)
	October	7.48 (6.65~9.23)	161.0 (45.3~539.0)	67 (16~111)	3.17 (1.07~5.70)
	Mean	7.63	142.5	57	3.01
Guri	April	7.91 (6.35~9.75)	278.9 (133.6~622.0)	68 (10~110)	3.26 (0.08~7.91)
	June	7.27 (6.89~8.54)	286.6 (138.0~617.0)	101 (40~165)	4.89 (1.82~9.70)
	August	7.58 (6.41~9.84)	257.4 (84.6~673.0)	124 (13~698)	4.02 (0.66~8.55)
	October	7.10 (5.73~9.08)	342.9 (72.3~534.0)	82 (41~272)	4.03 (0.65~9.28)
	Mean	7.46	291.5	94	4.05
Daegwan -ryoung	April	7.20 (6.78~8.15)	98.1 (18.6~192.5)	57 (10~216)	2.32 (0.56~4.71)
	June	7.45 (6.90~8.33)	114.8 (29.4~291.7)	39 (10~52)	3.77 (1.03~10.21)
	August	7.29 (6.81~9.20)	97.9 (22.9~227.0)	62 (16~165)	2.92 (0.33~10.68)
	October	7.02 (6.42~8.54)	100.2 (25.7~483.0)	58 (41~157)	3.46 (0.11~6.19)
	Mean	7.24	102.7	54	3.12
Dunnae	April	7.44 (7.06~8.26)	114.8 (53.9~286.3)	54 (46~98)	1.94 (0.40~5.03)
	June	7.32 (6.95~8.85)	143.3 (64.2~435.0)	49 (12~57)	2.96 (0.58~6.70)
	August	7.26 (6.82~7.68)	116.3 (59.6~330.0)	67 (45~88)	3.10 (0.69~5.49)
	October	7.17 (6.56~7.88)	139.0 (67.1~188.2)	55 (49~128)	3.44 (0.91~4.46)
	Mean	7.30	128.4	56	2.86

Table 2. Nitrogen concentrations in the stream water samples from the four different catchments (1995-1999).

Area	Month	Total-N ($mg \cdot L^{-1}$)	NH_4^+-N ($mg \cdot L^{-1}$)	NO_3^--N ($mg \cdot L^{-1}$)	NH_4^+/NO_3^-
Chunchon	April	4.26 (2.35~7.30)	0.44 (0.00~5.41)	4.76 (0.68~13.19)	0.09
	June	5.11 (1.72~6.78)	0.39 (0.00~6.10)	1.55 (0.49~14.90)	0.25
	August	4.11 (1.68~22.50)	0.55 (0.00~5.30)	2.18 (0.35~8.87)	0.25
	October	3.89 (1.68~20.48)	1.08 (0.08~5.26)	2.37 (0.70~8.87)	0.46
	Mean	4.34	0.62	2.71	0.26
Guri	April	17.01 (2.35~61.16)	0.85 (0.04~6.37)	9.65 (0.71~94.18)	0.09
	June	12.98 (3.84~47.21)	1.30 (0.01~7.24)	8.68 (0.71~16.47)	0.15
	August	12.27 (2.84~49.25)	1.17 (0.01~7.89)	5.87 (0.97~103.22)	1.00
	October	6.26 (1.68~39.88)	2.18 (0.06~5.98)	7.32 (0.16~18.21)	0.30
	Mean	12.13	1.37	7.88	0.39
Daegwan -ryoung	April	13.24 (1.35~57.27)	0.32 (0.00~3.61)	6.17 (1.01~11.42)	0.05
	June	8.54 (2.78~37.27)	0.26 (0.01~2.41)	2.99 (0.98~11.35)	0.09
	August	8.99 (1.68~28.00)	1.12 (0.00~2.66)	3.25 (0.42~36.94)	0.34
	October	4.35 (1.68~18.11)	0.86 (0.00~6.57)	3.16 (0.01~10.20)	0.27
	Mean	8.78	0.64	3.89	0.19
Dunnae	April	13.72 (5.73~39.95)	0.08 (0.00~0.15)	10.37 (3.51~59.04)	0.01
	June	10.36 (3.75~34.21)	0.10 (0.00~0.21)	5.84 (0.47~13.20)	0.02
	August	6.86 (1.68~25.60)	0.60 (0.14~0.82)	4.28 (1.88~20.26)	0.14
	October	5.05 (1.68~28.00)	1.02 (0.00~1.74)	4.68 (1.79~15.72)	0.22
	Mean	8.99	0.45	6.29	0.10

Guri area were higher than those in the other catchments (Table 2). Averaged NO_3^--N concentrations in Chunchon, Guri, Daegwanryung and Dunnae area were 2.71, 7.88, 3.89, and 6.29, respectively. Ratio of NH_4^+/NO_3^- ranged from 0.10 to 0.39, which indicates higher concentration of NO_3^- than that of NH_4^+ in stream water. Industrial and domestic sewage as well as agricultural practices might contribute these higher N concentration in Guri area. The N concentration in Daegwanryoung area appeared to increase as livestock and alpine farming practices increased. Water quality in Chunchon area was least deteriorated solely based on N concentration due to massive water flow from upper reaches of Soyang River. FAO evaluated NO_3^--N concentration of irrigation water for crop production (FAO, 1977), reporting that irrigation water containing less than 5 $mg \cdot L^{-1}$ concentration of NO_3^--N does not cause any risk for crop production. They also suggested that use of irrigation water containing greater than 30 $mg \cdot L^{-1}$ of NO_3^--N could cause adverse effect on crop production. Jung et al. (1997) suggested guideline for applying N-fertilizer on farming field based on several levels of NO_3^--N concentration

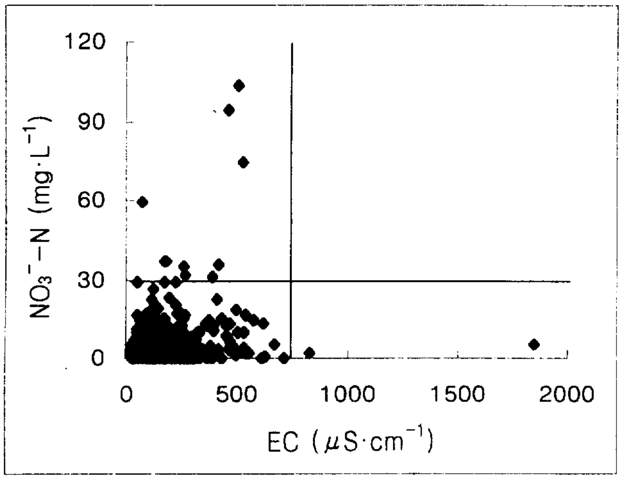

Fig. 1. Distribution of NO_3^--N and EC of the stream water

of irrigation water. They reported that application of irrigation water containing 30 $mg \cdot L^{-1}$ of NO_3^--N in farming area during growing season was approximately equivalent to application rate of 20 kg $N \cdot 10a^{-1}$. The recommended N-fertilizer application rate for vegetable crops ranged from 20 to 30 kg N $10a^{-1}$. Based on Jung et al. (1997), irrigation water quality was classified by three water quality factors; NO_3^--N, NH_4^+-N, and EC. Fig. 1 shows distribution of NO_3^--N and EC of the stream water. Out of more than 700 samples, 1.38% of samples exceeded 30 mg NO_3^--N L^{-1}. The 1.68% of samples exceeded both EC and NO_3^- level.

Total P, PO_4^{3-}, Cl^- and SO_4^{2-}

PO_4^{3-}-P concentrations in streams in Guri area were 0.59 mg L^{-1} with the range from trace to 7.29 $mg \cdot L^{-1}$. Concentrations of Cl^-, and SO_4^{2-} were 8.99 $mg \cdot L^{-1}$ with the range from 1.08 to 76.68 $mg \cdot L^{-1}$, and 34.36 $mg \cdot L^{-1}$ with range from trace to 7.89 $mg \cdot L^{-1}$, respectively (Table 3). All of the anion concentrations in Guri area showed higher values than the other catchments. For the streams in Chunchon area, Cl^- concentration was highest among anions, however, lower than that in stream in Guri area. For the streams in Daegwanryoung area, Cl^-, and SO_4^{2-} concentrations were lower than 10 $mg \cdot L^{-1}$, but streams in near resort area and livestock fields had more than 10 Cl $mg \cdot L^{-1}$. Sharpley et al. (1996) suggested that, based on the EPA standard, less than 1.0 $mg \cdot L^{-1}$ in runoff from a farming field should be kept. This suggestion implies that agricultural irrigation water containing less than 1.0 $mg \cdot L^{-1}$ could be applied to field for crop production.

Table 3. Total-P and anion concentrations in the stream water samples collected from four catchments (1995-1999).

Area	Month	Total-P ($mg \cdot L^{-1}$)	PO_4^{3-} ($mg \cdot L^{-1}$)	Cl^- ($mg \cdot L^{-1}$)	SO_4^{2-} ($mg \cdot L^{-1}$)
Chunchon	April	0.87 (0.02~2.89)	0.36 (0.00~2.75)	20.25 (2.07~25.66)	9.48 (2.98~17.87)
	June	0.43 (0.00~9.22)	0.46 (0.00~9.28)	10.15 (0.05~17.28)	9.78 (0.88~32.71)
	August	0.31 (0.00~2.53)	0.65 (0.00~0.76)	6.86 (1.09~39.61)	7.15 (1.06~26.92)
	October	0.30 (0.00~2.51)	0.17 (0.00~1.09)	9.97 (0.88~25.06)	9.62 (0.70~36.92)
	Mean	0.48	0.41	11.81	9.01
Guri	April	1.15 (0.08~15.18)	0.73 (0.05~3.08)	25.42 (6.37~54.32)	35.71 (5.24~136.48)
	June	0.94 (0.00~12.52)	0.56 (0.00~1.62)	18.41 (3.40~24.88)	30.81 (0.00~110.53)
	August	1.16 (0.01~3.12)	0.77 (0.00~1.68)	16.87 (1.09~47.96)	36.17 (7.25~109.6)
	October	0.99 (0.00~3.29)	0.46 (0.00~6.14)	17.49 (1.08~51.22)	38.15 (0.85~157.89)
	Mean	1.06	0.63	19.54	35.21
Daegwan -ryoung	April	0.44 (0.02~7.34)	0.08 (0.00~0.33)	7.79 (0.50~27.02)	7.02 (4.31~19.80)
	June	0.63 (0.00~5.94)	0.35 (0.00~0.83)	6.80 (0.00~19.11)	9.03 (0.00~45.06)
	August	0.31 (0.00~2.13)	0.15 (0.00~0.72)	8.41 (2.58~29.48)	6.05 (0.00~15.85)
	October	0.54 (0.00~2.09)	0.20 (0.00~0.51)	10.90 (1.06~12.63)	10.54 (1.24~20.86)
	Mean	0.48	0.19	8.47	8.16
Dunnae	April	0.95 (0.03~2.66)	0.03 (0.00~0.32)	10.78 (5.86~32.72)	11.92 (5.11~21.92)
	June	0.62 (0.00~15.00)	0.01 (0.00~0.13)	12.74 (3.19~15.32)	17.48 (5.25~42.27)
	August	0.38 (0.00~1.72)	0.00 (0.01~0.18)	8.07 (4.01~18.97)	11.03 (5.01~25.60)
	October	0.54 (0.00~2.98)	0.00 (0.00~0.24)	10.12 (3.17~21.02)	16.76 (9.29~12.40)
	Mean	0.62	0.01	10.43	14.30

Cations and heavy metals

Table 4 and 5 show cation and heavy metal concentrations in water samples taken from different catchments. Cation concentrations in streams in Guri area were in the order of Na>Ca>K>Mg, and all the cation concentrations in streams in Guri area had higher values than those in streams in the other areas. Since parent materials, domestic sewage, fertilizer application and precipitation play a major role for increasing cations in streams, we could control cation concentration in streams by reducing domestic sewage and fertilizer input.

Table 4. Cation concentrations in the stream water samples collected from four experimental catchments (1995-1999).

Area	Month	Cation concentration in stream water($mg \cdot L^{-1}$)			
		Ca	Mg	K	Na
Chunchon	April	4.98 (0.60~32.02)	3.89 (0.66~12.08)	1.61 (0.63~11.92)	4.25 (1.01~7.09)
	June	11.61 (0.76~21.23)	3.61 (0.48~4.61)	2.44 (1.63~8.50)	9.22 (2.40~15.06)
	August	5.28 (0.49~35.82)	2.77 (0.03~11.38)	2.17 (0.16~6.06)	6.83 (1.90~17.94)
	October	5.63 (0.43~36.56)	2.83 (0.45~6.56)	2.21 (0.19~5.52)	5.67 (1.53~20.87)
	Mean	6.88	3.27	2.11	6.49
Guri	April	4.74 (1.29~8.45)	3.79 (1.36~12.90)	4.21 (1.27~12.35)	14.15 (4.03~26.66)
	June	9.73 (2.46~20.45)	5.53 (1.96~16.98)	8.94 (2.34~15.06)	17.43 (4.76~33.17)
	August	7.69 (0.68~25.08)	7.17 (1.16~16.75)	9.39 (1.75~21.14)	14.20 (0.58~25.97)
	October	8.58 (0.02~26.25)	5.12 (1.11~20.33)	6.40 (0.31~21.42)	16.35 (0.76~31.06)
	Mean	7.68	5.40	7.23	15.53
Daegwan-ryoung	April	1.93 (0.11~6.08)	1.01 (0.06~2.30)	1.32 (0.13~7.10)	4.01 (0.41~20.76)
	June	5.14 (0.28~9.14)	3.04 (0.47~3.63)	2.10 (0.23~7.90)	8.14 (2.59~19.13)
	August	3.65 (0.31~6.71)	1.75 (0.02~3.25)	2.12 (0.11~9.26)	7.59 (1.01~14.92)
	October	3.06 (0.06~6.18)	1.43 (0.20~6.30)	1.25 (0.12~9.14)	6.51 (0.52~15.34)
	Mean	3.44	1.81	1.70	6.56
Dunnae	April	6.27 (1.10~25.39)	2.16 (0.94~12.06)	1.70 (0.85~5.49)	4.94 (1.10~12.48)
	June	5.06 (1.49~19.62)	2.47 (0.90~16.93)	2.66 (0.62~16.32)	6.34 (3.82~14.46)
	August	6.48 (0.64~18.83)	1.33 (0.84~3.89)	2.08 (0.07~6.32)	7.11 (2.68~16.33)
	October	6.11 (1.51~18.54)	2.29 (0.95~6.62)	2.38 (0.69~4.82)	7.28 (0.38~10.10)
	Mean	5.98	2.06	2.20	6.42

Therefore, we need strategy for reducing domestic sewage and fertilizer use. Cu concentration level which could damage crops is 0.18 $mg \cdot L^{-1}$ or above. Averaged Cu concentrations ranging from 0.03 to 0.04 $mg \cdot L^{-1}$ in four catchments were not significantly different, however, in some sites, we detected much higher Cu concentration than 0.18 $mg \cdot L^{-1}$. Zn limitation level for crop is 7.4 $mg \cdot L^{-1}$ (MOE, 2000). All of the averaged Zn concentrations ranging from 0.17 to 0.29 $mg \cdot L^{-1}$ in four catchments would not cause Zn overdose problem to crops. The highest Zn level of 6.98 $mg \cdot L^{-1}$ detected in stream in Chunchon on June 1998 did not exceed limitation level. Averaged Fe concentration in four catchments had highest values among heavy metal concentrations. Kim et al. (1999) reported that, because of easy removal of Fe in water by aeration and sedimentation, it is desirable to conduct pretreatments such as aeration and sedimentation for highly Fe containing streams before using as irrigation water. Averaged Cd concentrations in four catchments ranged from 0.002 to 0.004 $mg \cdot L^{-1}$. Averaged Mn concentrations ranged from 0.06 to 0.14 $mg \cdot L^{-1}$. Cr was not detectable. Particularly heavy metal concentrations in Wangsuk streams in Guri area were higher due to sludge and sewage input from factories manufacturing leather and furniture etc.

Ground water quality

Table 6 shows comparison of water quality between streams and ground water in Guri area. Averaged pH in ground water was 6.38 (5.60~7.37), and averaged EC in ground water was 499 $\mu S \cdot cm^{-1}$ (165~1082 $\mu S \cdot cm^{-1}$), while averaged pH in stream water was 7.42 (5.73~9.84), and averaged EC in stream was 289 $\mu S \cdot cm^{-1}$ (72~1845 $\mu S \cdot cm^{-1}$). NO_3^--N concentration in ground water was higher than those in stream. Especially NO_3^--N in ground water showed two times higher concentration than that in stream. High concentration of NO_3^--N in ground water could arise problem for irrigation purpose. In contrast, NH_4^+-N concentration in ground water were 1.6 times lower than those in stream. Cl^- (35 $mg \cdot L^{-1}$) and SO_4^{2-} (52 $mg \cdot L^{-1}$) concentrations in ground

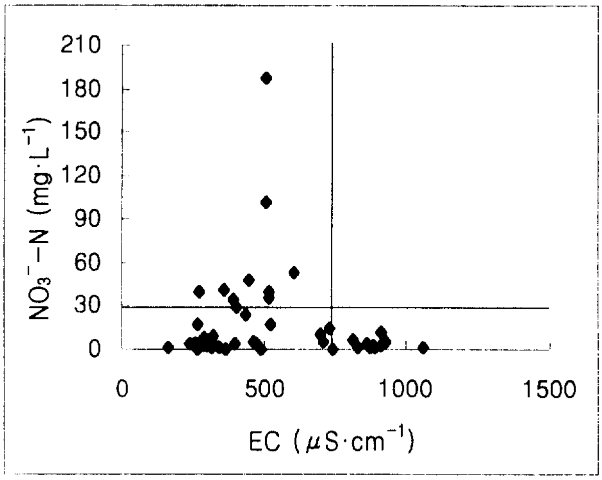

Fig. 2. Distribution of NO_3^--N and EC of the ground water

Table 5. Heavy metal concentrations in the stream water samples collected from four experimental catchments (1995-1999).

Area	Month	Heavy metal concentration in stream water(mg·L^{-1})				
		Cd	Cu	Cr	Fe	Mn
Chunchon	April	0.003 (0.0~0.016)	0.00 (0.00~0.05)	0.00 (0.00~0.03)	0.51 (0.01~1.49)	0.05 (0.00~0.12)
	June	0.005 (0.0~0.00)	0.07 (0.00~0.90)	0.00 (0.00~0.03)	1.20 (0.02~3.10)	0.29 (0.00~1.60)
	August	0.003 (0.0~0.012)	0.04 (0.00~0.09)	0.00 (0.00~0.02)	0.57 (0.00~1.60)	0.04 (0.00~0.10)
	October	0.003 (0.0~0.010)	0.03 (0.00~0.09)	0.00 (0.00~0.01)	0.44 (0.02~1.70)	0.05 (0.00~0.09)
	Mean	0.003	0.03	0.00	0.68	0.11
Guri	April	0.001 (0.0~0.009)	0.03 (0.00~0.27)	0.00 (0.00~0.02)	0.58 (0.00~1.37)	0.12 (0.00~0.31)
	June	0.002 (0.00~0.09)	0.01 (0.00~0.11)	0.00 (0.00~0.05)	0.48 (0.00~1.23)	0.10 (0.00~0.40)
	August	0.05 (0.0~0.013)	0.09 (0.00~0.13)	0.00 (0.00~0.00)	1.60 (0.30~2.50)	0.19 (0.00~0.59)
	October	0.003 (0.0~0.010)	0.03 (0.00~0.13)	0.00 (0.00~0.01)	0.65 (0.31~1.98)	0.15 (0.02~1.16)
	Mean	0.002	0.04	0.00	0.83	0.14
Daegwanryoung	April	0.001 (0.0~0.022)	0.01 (0.00~0.09)	0.00 (0.00~0.02)	0.52 (0.00~1.72)	0.07 (0.00~0.38)
	June	0.001 (0.0~0.012)	0.02 (0.00~0.14)	0.00 (0.00~0.10)	0.57 (0.00~6.71)	0.10 (0.00~1.12)
	August	0.003 (0.0~0.012)	0.04 (0.00~0.09)	0.00 (0.00~0.00)	0.82 (0.00~2.05)	0.07 (0.00~1.34)
	October	0.003 (0.0~0.011)	0.04 (0.00~0.09)	0.00 (0.00~0.03)	0.75 (0.05~3.63)	0.11 (0.00~0.36)
	Mean	0.002	0.03	0.00	0.66	0.08
Dunnae	April	0.01 (0.0~0.014)	0.01 (0.00~0.08)	0.00 (0.00~0.01)	0.41 (0.00~0.92)	0.06 (0.00~0.38)
	June	0.00 (0.0~0.01)	0.02 (0.01~0.06)	2.66 (0.00~0.00)	0.19 (0.00~0.90)	0.04 (0.00~0.26)
	August	0.005 (0.0~0.011)	0.05 (0.02~0.09)	0.00 (0.00~0.00)	0.43 (0.00~1.33)	0.05 (0.00~0.75)
	October	0.003 (0.0~0.009)	0.03 (0.03~0.14)	0.00 (0.00~0.00)	0.74 (0.05~1.1)	0.07 (0.00~0.19)
	Mean	0.002	0.03	0.00	0.44	0.05

water were 1.8 times, 1.5 times higher than those in stream water, however, far below than Cl^- limitation level (250 mg L^{-1}) of ground water as irrigation purpose. PO_4^{3-} concentration in ground water and stream were 0.03 mg·L^{-1} (<0.01 ~0.22) and 0.59 mg L^{-1} (<0.01 ~7.29), respectively. Fig. 2 shows the distribution of NO_3^--N and EC of ground water. 22.0% out of ground water samples had greater than 30 NO_3^--N mg · L^{-1}. Evaluating both NO_3^--N and EC, 40% from samples exceed either factor, which indicate ground water should be used more carefully as irrigation water than stream water.

USDA Salinity Staff (1953) considered EC as one of the most important indicators to estimate water quality for irrigation purpose. They reported that use of irrigation water which has more than 750 μS·cm^{-1} should be limited to crops which are tolerant to salinity damage or special purposes.

Statistical factor analysis of the stream water indicators

Table 7 shows the statistics of water quality indicators analyzed for 713 samples. pH ranged from 2.80 to 10.20 with mean of 7.55, but the standard deviation was 0.62 and the CV was 8 percents. It implied that pH of surface water in the agricultural area was not varied. The most variable indicator was PO_4^{3-}-P.

Table 6. Comparison of water quality between Guri stream water and ground water.

	Stream water	Ground water
pH	7.42 (5.73~9.84)	6.38 (5.60~7.37)
EC($\mu S \cdot cm^{-1}$)	289.4 (72.3~673.0)	498.9 (165.7~1082.0)
NH_4-N($mg \cdot L^{-1}$)	1.38 (0.01~7.89)	0.85 (0.01~3.32)
NO_3-N($mg \cdot L^{-1}$)	8.75 (0.16~103.22)	18.00 (0.74~188.01)
PO_4($mg \cdot L^{-1}$)	0.59 (0.00~6.14)	0.03 (0.00~0.22)
Cl($mg \cdot L^{-1}$)	18.99 (1.08~54.32)	35.01 (0.00~223.24)
SO_4($mg \cdot L^{-1}$)	34.36 (0.00~157.89)	52.81 (5.01~342.82)
COD($mg \cdot L^{-1}$)	4.01 (0.08~9.70)	2.82 (0.41~7.39)

Table 7. Statistics of stream water quality indicators

Variable		Mean[a]	S.D.[b]	CV(%)	Min	Max
pH		7.55	0.62	8	2.80	10.20
EC	$\mu S \cdot cm^{-1}$	165.45	126.77	76	18.60	1845.00
Ca	$mg \cdot L^{-1}$	5.99	7.58	126	0.001	65.80
K	$mg \cdot L^{-1}$	3.71	5.42	113	0.10	51.40
Na	$mg \cdot L^{-1}$	9.09	12.01	146	0.001	152.90
Total-N	$mg \cdot L^{-1}$	10.24	10.94	132	0.001	87.00
TSS	$mg \cdot L^{-1}$	78.31	69.30	106	0.001	698.00
NH_4^+-N	$mg \cdot L^{-1}$	0.83	1.25	88	0.001	8.20
NO_3^--N	$mg \cdot L^{-1}$	5.37	8.30	150	0.001	103.20
Total-P	$mg \cdot L^{-1}$	0.62	0.82	154	0.001	5.60
PO_4^{3-}	$mg \cdot L^{-1}$	0.37	1.13	132	0.001	9.30
Cl	$mg \cdot L^{-1}$	10.29	21.03	305	0.001	256.60
SO_4^{2-}	$mg \cdot L^{-1}$	14.40	20.19	204	0.001	216.70
COD	$mg \cdot L^{-1}$	3.12	2.27	140	0.10	22.50
Cd	$mg \cdot L^{-1}$	0.004	0.005	72	0.001	0.040
Cu	$mg \cdot L^{-1}$	0.05	0.14	125	0.001	2.40
Cr	$mg \cdot L^{-1}$	0.0002	0.0004	280	0.000	0.1000
Fe	$mg \cdot L^{-1}$	0.79	1.30	200	0.001	19.80
Mn	$mg \cdot L^{-1}$	0.10	0.15	165	0.001	1.30
Zn	$mg \cdot L^{-1}$	0.34	0.77	226	0.001	8.80

[a]: averaged over 713 observations.

[b]: standard deviation.

In the 21 X 21 cross correlation matrix, 81 correlations were significant out of 231 water quality indicator pairs (Table 8). EC was most significantly correlated with 14 indicators. The correlation coefficients with Ca^{++}, Mg^{++}, K^+, Na^+, T-N, TSS, NH_4^+-N, NO_3^--N, T-P, PO_4^{3-}, Cl, SO_4^{--}, COD and Mn were significant at P = 0.001 level. EC showed no correlation with pH, Cd, Cu, Cr, Fe, and Zn. KMO measure provides a means to assess the extent to which the indicators of construct belong together. Therefore, a higher value of KMO is desired. Overall KMO (Kaiser-Meyer-Olkin) value for EC was 0.80 which was acceptable, however, the KMO values for T-N, Cr, Fe, and Zn were lower than 0.50.

Table 9 shows the factor analysis of the correlation matrix after the VARIMAX rotation procedure in SAS. Eigenvalues for the first six factors by principal component analysis were greater than 1.0 and accounted for 63.49 percents of the total variance. Therefore, six factors were chosen for the rotation.

The first factor accounts for 27.01 percents of the total variance, and showed high factor loadings with EC, K, Na, NH_4^+-N, TSS, PO_4^{3-}, SO_4^{2-}, and COD. Loadings of these eight indicators were higher than 0.5 and those of other indicators were lower than 0.5. Among these indicators, five indicators were solution electrolyte components which directly govern electrical conductivity (EC). Therefore, the first factor could be characterized as EC factor.

The second factor showed high loadings with Cu, and Zn. This factor could be characterized as the heavy metal factor.

The third to sixth factors could be characterized as a Mg factor, a NO_3^--N factor, an pH factor, and Fe factor, respectively.

The plot of factor pattern for factor 1 and factor 2 of stream water are shown in Fig. 3.

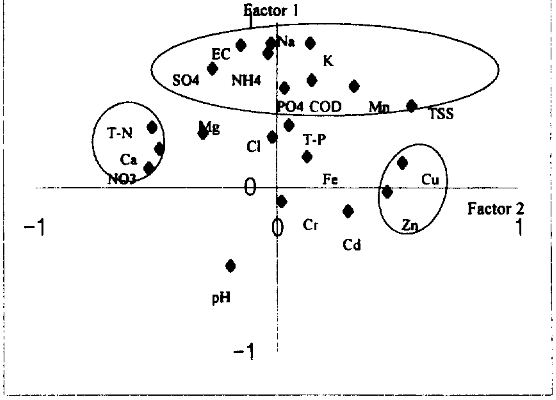

Fig. 3. Plot of factor pattern for factor 1 and factor 2 of stream water

Table 8. Correlation matrix and KMO values of the stream water quality indicators.

	pH	EC	Ca	Mg	K	Na	T-N	TSS	NH_4^+-N
pH	1.00								
EC	-0.08^{*}	1.00							
Ca	0.16^{***}	0.23^{***}	1.00						
Mg	0.14^{*}	0.34^{***}	0.48^{***}	1.00					
K	-0.15^{**}	0.63^{***}	0.20^{***}	0.45^{***}	1.00				
Na	-0.14^{**}	0.73^{***}	0.20^{***}	0.27^{***}	0.70^{***}	1.00			
T-N	0.02	0.19^{***}	-0.03	0.17^{**}	0.25^{***}	0.18^{***}	1.00		
TSS	-0.11^{*}	0.28^{***}	-0.08	0.14^{*}	0.52^{***}	0.33^{***}	0.02	1.00	
NH_4^+-N	-0.13^{**}	0.40^{***}	-0.03	0.06	0.46^{***}	0.46^{***}	0.32^{***}	0.29^{***}	1.00
NO_3^--N	-0.07	0.21^{***}	0.01	0.08	0.10^{*}	0.01	0.04	-0.01	0.02
T-P	0.03	0.24^{***}	0.18^{***}	0.20^{***}	0.20^{***}	0.19^{***}	0.12^{*}	0.18^{**}	0.01
PO_4^{3-}	-0.10^{*}	0.27^{***}	-0.01	0.01	0.25^{***}	0.43^{***}	-0.06	0.23^{**}	0.31^{***}
Cl	0.01	0.28^{***}	0.06	0.11^{*}	0.28^{***}	0.31^{***}	0.16^{*}	0.05	0.11^{*}
SO_4^{2-}	-0.16^{***}	0.65^{***}	0.12^{*}	0.18^{**}	0.49^{***}	0.61^{***}	0.29^{***}	0.23^{**}	0.27^{***}
COD	0.03	0.26^{***}	0.12^{*}	0.16^{***}	0.35^{***}	0.35^{***}	0.04	0.23^{***}	0.19^{***}
Cd	-0.05	-0.04	-0.26^{***}	-0.24^{***}	-0.15^{**}	-0.20^{***}	-0.06	-0.02	0.15^{*}
Cu	-0.06	-0.00	-0.10^{*}	-0.07	0.09	-0.05	-0.09	0.50^{***}	0.16^{**}
Cr	0.03	-0.03	-0.02	-0.01	-0.02	-0.02	-0.05	-0.06	-0.03
Fe	-0.15^{**}	0.05	-0.08	0.13^{*}	0.24^{***}	0.02	0.14^{*}	0.28^{***}	0.05
Mn	-0.15^{**}	0.32^{***}	-0.05	0.03	0.38^{***}	0.33^{***}	-0.01	0.20^{*}	0.30^{***}
Zn	0.07	0.01	0.04	-0.03	0.02	-0.01	0.19^{**}	-0.04	0.04
KMO	0.73	0.80	0.61	0.53	0.76	0.89	0.44	0.63	0.72

(Table 8: Continued)

	NO_3^--N	T-P	PO_4^{3-}	Cl^-	SO_4^{2-}	COD	Cd	Cu	Cr	Fe	Mn	Zn
NO_3^--N	1.00											
T-P	0.13^{*}	1.00										
PO_4	-0.05	0.08	1.00									
Cl	0.11^{*}	0.19^{***}	0.03	1.00								
SO_4	0.20^{***}	0.24^{***}	0.10^{*}	0.35^{***}	1.00							
COD	-0.13^{**}	0.14^{**}	0.45^{***}	0.05	0.12^{*}	1.00						
Cd	0.10^{*}	-0.10^{*}	-0.33^{***}	0.02	-0.05	-0.19^{***}	1.00					
Cu	-0.03	0.02	0.17^{*}	-0.07	-0.03	0.17^{**}	0.20^{***}	1.00				
Cr	-0.03	-0.03	-0.02	-0.02	-0.01	-0.01	-0.04	-0.02	1.00			
Fe	0.12^{*}	0.13^{*}	-0.07	0.01	0.03	0.08	0.07	-0.00	0.03	1.00		
Mn	0.01	0.11^{*}	0.10	0.18^{***}	0.23^{***}	0.18^{***}	0.16^{**}	0.10^{*}	-0.03	0.15^{*}	1.00	
Zn	-0.10^{*}	-0.02	0.46^{***}	0.03	-0.05	0.35^{***}	-0.13^{*}	0.15^{*}	-0.01	-0.06	0.07	1.00
KMO	0.50	0.78	0.81	0.84	0.75	0.89	0.62	0.51	0.45	0.43	0.76	0.31

Table 9. Factor loadings of the stream water quality indicators.

Indicators	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Final communality
Eigenvalue	5.673	2.055	1.641	1.466	1.367	1.130	
Proportion(%)	27.01	9.78	7.81	6.98	6.51	5.38	
Cumulative	27.01	36.80	44.61	51.59	58.10	63.49	
pH	-0.466	-0.192	-0.168	0.236	0.409	-0.193	0.567
EC	0.859	-0.145	0.229	-0.017	0.120	0.072	0.840
Ca	0.230	-0.482	-0.246	-0.100	0.407	-0.176	0.692
Mg	0.335	-0.305	0.447	-0.023	0.370	0.095	0.754
K	0.873	0.138	0.634	-0.110	0.058	0.113	0.861
Na	0.868	-0.023	0.225	-0.195	0.158	0.017	0.848
T-N	0.369	-0.514	-0.175	0.380	-0.349	-0.025	0.667
TSS	0.489	0.558	0.014	0.143	-0.152	-0.047	0.781
NH_4^+-N	0.812	-0.033	0.430	-0.097	0.000	-0.163	0.707
NO_3^--N	0.115	-0.527	-0.099	0.536	-0.298	0.138	0.698
T-P	0.374	0.051	0.112	0.393	-0.141	-0.412	0.487
PO_4^{3-}	0.600	0.032	0.033	-0.234	-0.277	-0.229	0.582
Cl^-	0.306	-0.116	-0.193	0.445	0.278	0.199	0.518
SO_4^{2-}	0.716	-0.263	-0.311	0.105	-0.023	0.018	0.663
COD	0.651	0.146	-0.264	-0.080	0.089	0.079	0.499
Cd	-0.146	0.297	0.181	0.466	0.258	0.122	0.490
Cu	0.156	0.520	-0.287	0.307	-0.173	-0.427	0.716
Cr	-0.077	0.024	0.339	-0.220	-0.059	0.223	0.108
Fe	0.184	0.126	-0.012	0.073	-0.388	0.645	0.799
Mn	0.610	0.322	0.421	0.098	0.249	0.077	0.577
Zn	-0.024	0.459	-0.155	0.300	0.354	0.222	0.478

Ground water quality analysis

Statistics of ground water quality indicators in Guri were run for 58 samples.

In the 20 X 20 cross correlation matrix, 53 correlations were significant out of 190 ground water quality indicator pairs. EC was significantly correlated with 10 indicators. The correlation coefficients with pH, Ca, Mg, and Na were significant at P = 0.001 level.

The first factor out of six factors whose eigenvalues were greater than 1.00 by factor analysis of the correlation matrix accounts for 28.54 percents of the total variance, and showed high factor loadings with pH, EC, Ca, Mg, K, Na, NH_4^+-N, SO_4^{-2}, COD, and Mn. Among these indicators, seven indicators were solution electrolyte components which directly govern electrical conductivity (EC). The second factor showed high loadings with Cd, Cu, and Zn. This factor could be characterized as the heavy metal factor (data not shown). Fig. 4 shows the plot of factor pattern for factor 1 and factor 2 of ground water. pH was not grouped into factor 1 in stream water as shown in Fig. 3. In contrast, pH was grouped into factor 1 in ground water as shown in Fig. 4. TSS was not grouped into factor 1 in ground water, but grouped into factor 1 in stream water. These results imply that TSS plays a minor role for determining water quality in ground water, but major role in stream water.

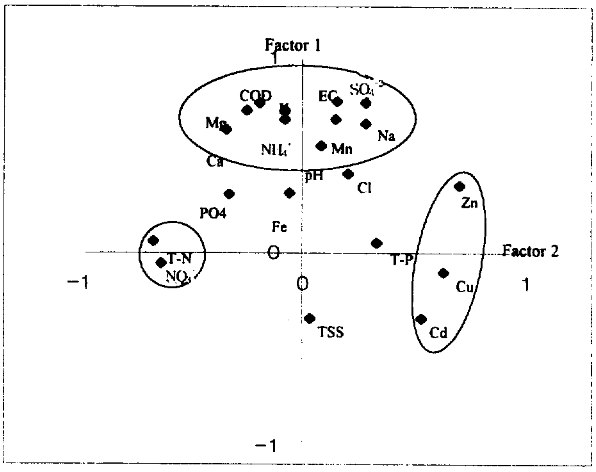

Fig. 4. Plot of factor pattern for factor 1 and factor 2 of ground water

Table 10 . Factor loadings of the reservoir water quality indicators.

Factor	Eigenvalue	Cumulative	Indicator
1	4.447	37.06	EC, Ca, Mg, K, Na, TSS, T-P, Cl^-, COD
2	2.413	57.16	EC, Ca Mg
3	1.301	68.00	Cu
4	1.018	76.48	-

Reservoir water quality analysis

Statistics of reservoir water quality indicators were run for 48 samples collected by KARICO (1999). Table 10 shows the factor analysis of the correlation matrix after the VARIMAX rotation procedure in SAS. Eigenvalues for the first four factors by principal component analysis were greater than 1.0 and accounted for 76.48 percents of the total variance. Therefore, four factors were chosen for the rotation.

The first factor accounts for 37.06 percents of the total variance, and showed high factor loadings with EC, Mg, K, Na, SS, T-P, Cl^-, and COD. Among these indicators, five indicators were solution electrolyte components which directly affect electrical conductivity (EC). Therefore, the first factor could be termed as EC factor.

Differently from the surface water, the EC, Ca and Mg appeared to the second factor again.

The third factor showed high loadings with Cu. This factor could be termed as a heavy metal factor.

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