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Assessment of Long-Term Physicochemical Water Quality Variations by PCA Technique in Lake Hwajinpo, South Korea

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Abstract

Physicochemical properties of water were analyzed to assess the long-term water quality variations in Lake Hwajinpo, Korea. Water quality data monitored from 1998 to 2015 was divided in three periods and descriptive statistics, correlation and rotated components were deducted using statistical procedures. Based on the results of analyses, water quality patterns in three periods (1998-2003, 2004-2009 and 2013-2015) were distinguishable from each other. Water parameters, Chlorophyll-a, total phosphorus, total nitrogen, dissolved oxygen and pH, showed the highest mean values in the first period. On the other hand, conductivity and salinity in the second period and temperature and suspended solids in the third period showed the highest mean values. Principal component analysis (PCA) procedure was utilized to deduct the most significant parameters influencing water quality and observed that each period had different pattern of variables. Salinity and conductivity were the two variables highly contributing in first component/factor (F1) explaining 20.77% and 22.93% of the total variance in the first period and second period, respectively. But total phosphorus and chlorophyll-a were the two variables highly loading in F1 of the third period explaining 23.72% of total variance. These results revealed that the water quality of Lake Hwajinpo had different patterns of variations throughout the study period. Thus, PCA results could be valuable to understand the water quality status of water body and take proper steps to protect the water environment.

Keywords

Physicochemical Parameters, Coastal Lagoon, PCA, Lake Hwajinpo

1. Introduction

Coastal lagoons are shallow water bodies separated from sea by barrier islands, coral reefs and sand bars. They have unique and rich habitats from sea to inland since they occupy the area between the sea and land. Along with lagoons, there may be habitats of barrier islands, spits, beaches, sand dunes, salt marshes and seagrasses to support biodiversity. The diverse ecosystem within the surrounding of lagoons plays important role to have high species of diversity and creates ecotones-area of transition between major habitats: marine, freshwater and terrestrial. The ecosystems of the lagoons were disturbed due to changes in climate and regional landscape [1] [2] [3]. Anthropogenic activities such as agriculture, aquaculture, urbanization, industrialization and recreational activities are major causes of water quality deterioration of lagoons. Eutrophication is the major threat to ecology and biological communities which arises because of high nutrient from point and non-point sources of pollution. Discharges from non-point source pollution such as agricultural and domestic water can cause the episodic eutrophication and algal blooms which can be toxic [4] [5] [6]. Lagoons receive sediments from rivers that flow into them and surface runoff. Therefore, coastal lagoons have a tendency to become filled with the sediments and thus disappear, in time, from the coastal landscape. Overuse of land and rapid industrialization are the main reason to the loss of lagoons area [7] [8]. The major threat to the existence and health of lagoons water body is human activities.

The lagoons in the Korean Peninsula are mainly distributed in the eastern coastline. Among the 57 natural lakes in this region 48 of them are marine origin natural lakes which were formed by sand dunes due to the ocean water currents [9] [10]. Lake Hwajinpo is one of the seven major lagoons in the eastern coast of Korea and the others are Youngrang, Kyoungpo, Sonji, Mae, Cheongcho and Gwangpo. The slope of the surface of the lake is gentle and the water level is stable throughout the year, and the wetland vegetation is well developed. Unlike the freshwater lake, Hwajinpo Lake is characterized by the combination of seawater and fresh water. It has the characteristics of brackish water. This lake has one inlet channel to exchange water with East Sea and can be categorized as the Choked lagoon [11]. Lake Hwajinpo was well protected lagoon in this region till 1991 because the public access was limited since it was designated as a military area. But later it was opened as a national recreation site and several infrastructures: museums, lodging and amusement facilities were built to attract visitors. These facilities along with increasing agricultural activities in the watershed causes high nutrient in the lagoon. The surface area of the lagoon has been slightly changed from 2.29 km^2 in 1918 to 2.06 km^2 in 2000 which is 90% of the initial lagoon area [7].

Water quality of coastal lagoons and other water bodies are very important for the ecosystem as well as human health. It is necessary to monitor and manage lagoons to abate any negative impact on its surrounding. A monitoring program is required to provide reliable measure of the quality of water bodies. Through data analysis, one can interpret and understand the nature of pollution [12]. The impact of natural and anthropogenic processes on the lagoon ecosystem could be identified by continuous monitoring and analyzing. Temporal and spatial water quality properties are helpful to recognize the changes and trend of lagoon water [13] [14]. Lake Hwajinpo and other major eastern coastal lagoons in Korea are regularly monitored since 1997 and ecosystem restoration efforts are made [15]. Previous literature of Lake Hwajinpo demonstrated eutrophication [10], limnological properties [16], landscape change [7] [9], water environment variation [17] and phytoplankton and trophic status [18].

The aim of this study is to assess the long-term temporal variations of physicochemical water quality of Lake Hwajinpo from 1998 to 2015. Descriptive water statistics and correlation were deducted and factor analysis (FA) was conducted to identify the important components or factor of water quality variables. The deduction of major parameters and grouping variables by multivariate techniques such as principal component analysis (PCA) enables to identify the sources of pollution [19] [20] [21]. Thus the result of this study will be helpful to water managers to understand the water quality status of Lake Hwajinpo and apply for further management.

2. Materials and Methods

2.1. Study Area

Lake Hwajinpo, a lagoon in the eastern coast of Korea, is located in Geojin township of Goseong County, Gangwon Province (**Figure 1**). The surface area of the lagoon is 2.06 km^2 with average depth 1.2 m and divided into two parts, North and South which are connected by a narrow channel. The watershed area

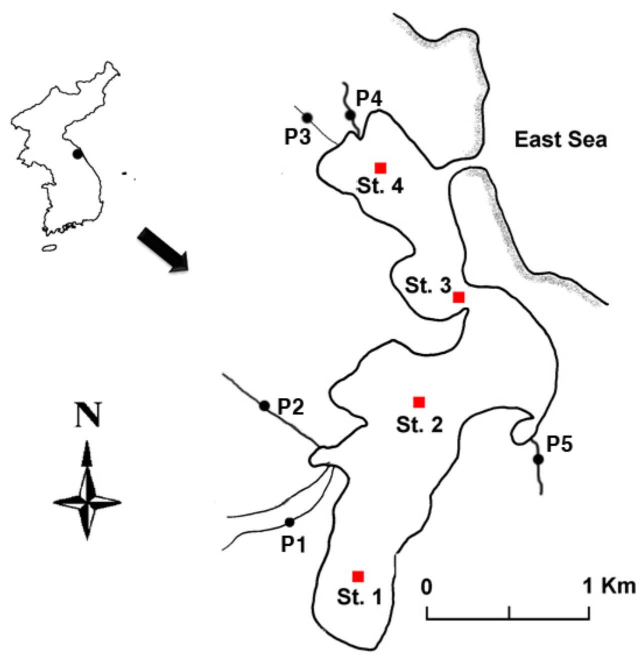

Figure 1. Map of the Lake Hwajinpo showing location in Korea and monitoring stations. The Geographic co-ordinates are Latitude 38˚45-48'N and Longitude 128˚42-44'.

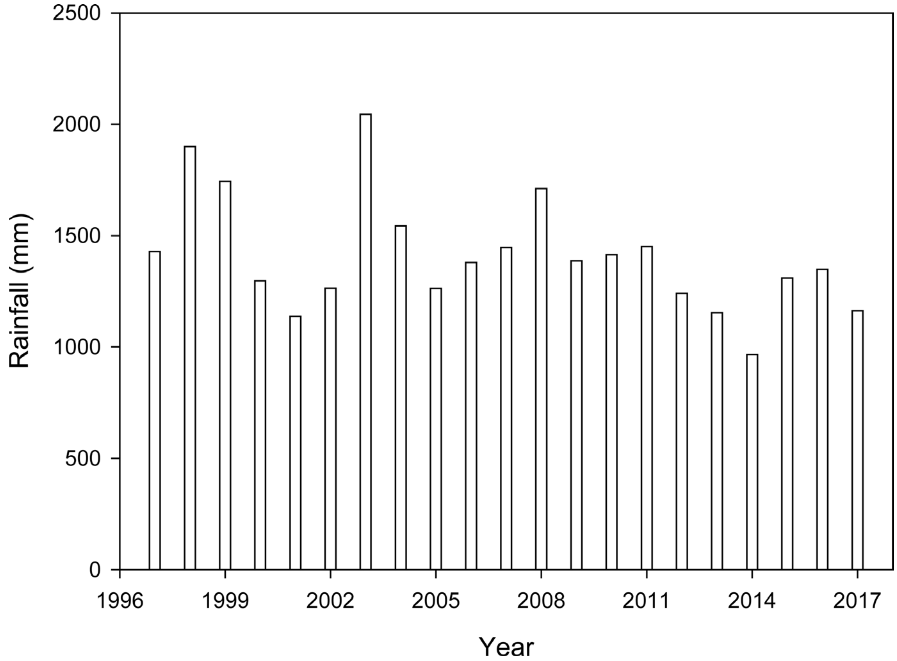

Figure 2. Annual rainfall in Goseong County, the basin of Lake Hwajinpo.

of the lagoon is 20.07 km^2 and inflowing river system is 21 km in length of 5 small streams, Jungpyeong being the main stream. The North part is connected to the East Sea and relatively less polluted than the South part. The South part of the lagoon does not mix properly with sea water since horizontal mixing with North part is rare due to the narrow channel and receives more non-point source pollution through stream inflow and stormwater runoff. The South part, three times larger than the North part, largely receives pollutants from forest, farms and paddy fields. The average N and P loading generation in Lake Hwajinpo are 242 and 66 kg/day and average annual rainfall of last 20 years is 1410 mm [16] (**Figure 2**).

2.2. Sampling and Measurements

Water quality was monitored from 1998 to 2009 and 2013-2015 in a monthly basis in 65 episodes from four sites, two in North and two in South, except the months of severe winter. Water temperature (Temp), electric conductivity (EC), salinity (Sal), dissolved oxygen (DO), Secchi disk transparency (SD), pH, suspended solids (SS), total phosphorus (TP), dissolved inorganic phosphorus (DIP), total nitrogen (TN), nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N) and Chlorophyll-a (Chl-a) were the physicochemical parameters chosen. Lorenzen's (1967) method was used to calculate chlorophyll-a concentration. Filtered water was used to calculate dissolved nitrogen and phosphorus. TP was determined according to standard methods APHA [22], employing persulfate digestion and ascorbic acid method. TN was determined by the cadmium reduction method after persulfate digestion, using a flow injection auto-analyzer (BRAN-LUEBBE, Auto Analyzer3). Temperature, salinity, EC, pH and DO were measured *in-situ* with a multi-probe meter (YSI, 6000).

2.3. Statistical Analyses

The data was divided in three periods as 1998-2003, 2004-2009 and 2013-2015 to understand the water quality variations in different periods. Box and whiskers plots for five parameters were presented in (Figure 3). Several outlier values were visible in each period. Therefore we chose to perform non-parametric tests.

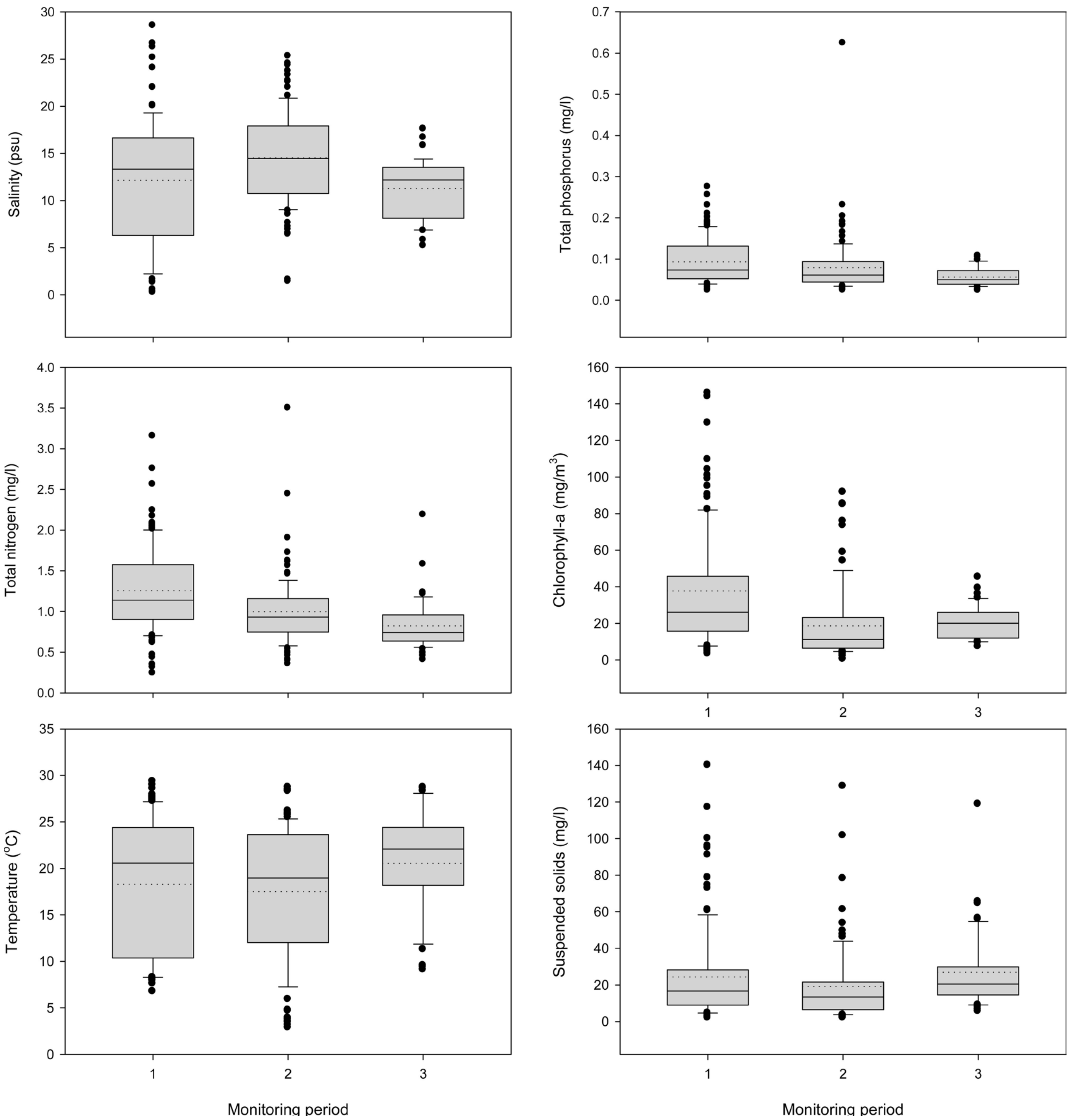

Figure 3. Box plots of water quality parameters. Mean, dotted line; median, dark line; box, 1st and 3rd quartiles; whiskers, mean ± standard deviation; outliers, dark points.

The non-parametric correlation and PCA/FA test were performed for statistical analysis in SPSS 19 software (IBM Corporation, Armonk, NY, USA). PCA helps to reduce dataset and it deducts dominant components which are valuable to have a better interpretation of variables. The details of these tests methods were detailed in these literatures [23] [24] [25].

3. Results and Discussion

3.1. Descriptive Water Quality Patterns

The descriptive statistics (mean, standard deviation etc.) physicochemical parameters of Lake Hwajinpo were presented in **Tables 1-3** for the period of 1998-2003, 2004-2009 and 2013-2015, respectively. The results showed that the highest mean values of temperature, SD transparency and SS were in period of 2013-2015 and conductivity, salinity and NO_3-N were in the period of 2004-2009. However, the highest mean values of DO, pH, Chl-a and nutrient components (TP, DIP and TN) were in the period of 1998-2003. There was not much variation of mean values of NH_3-N. The highest mean value of temperature was 20.6˚C in the latter part of study period and the minimum was 17.51˚C in 2004-2209. The highest mean values of SD and SS were 0.80 m and 27 mg/L, respectively. Salinity, conductivity and NO_3-N had the highest values as 25 psu, 2625 µs/cm and 0.08 mg/L in 2004-2009, respectively.

In the period of 1998-2003, the highest observed mean values of DO and pH were 10.56 mg/L and 9.3, respectively. Meanwhile, these two parameters had the lowest mean values in 2013-2015. The nutrient components had the maximum mean values in the earlier period of the study. And the lowest mean values were

Table 1. Descriptive statistics of surface water quality of Lake Hwajinpo from 1998-2003.

Parameters	Minimum	Maximum	Mean	Standard Error	Standard Deviation	Observations
Temp	6.70	29.4	18.3	0.645	7.19	124
Cond	427	47037	20761	983	10949	124
Sal	0.23	30	13	0.637	7.10	124
DO	0.56	27.12	**10.56**	0.386	4.29	124
pH	1.47	69.6	**9.331**	0.499	5.55	124
SD	0.20	1.7	0.656	0.030	0.34	124
TP	0.02	0.28	**0.093**	0.005	0.05	124
DIP	0.002	0.14	**0.017**	0.002	0.02	124
TN	0.003	3.15	**1.235**	0.048	0.54	124
NO_3N	0.040	1.00	0.061	0.011	0.13	124
NH_3N	0.004	0.47	0.134	0.011	0.13	124
Chl-a	3.00	146	37	2.810	31.29	124
SS	2.00	140	24	2.237	24.71	122
Valid N (listwise)						122

Temp, water temperature (˚C); SD, Secchi disk transparency (m); Sal, Salinity (psu); DO, dissolved oxygen (mg/L); COD, chemical oxygen demand (mg/L); SS, suspended solids (mg/L); TP, total phosphorus (mg/L); DIP, dissolved inorganic phosphorus (mg/L); TN, total nitrogen (mg/L); NO_3-N, nitrate nitrogen (mg/L); NH_3-N, ammonia nitrogen (mg/L) and Chl-a, chlorophyll-a (mg/m^3).

Table 2. Descriptive statistics of surface water quality of Lake Hwajinpo from 2004-2009.

Parameters	Minimum	Maximum	Mean	Standard Error	Standard Deviation	Observations
Temp	2.9	28.7	17.51	0.71	7.07	98
Cond	2625	39760	**23787**	748	7406	98
Sal	1.4	25.0	**15.0**	0.49	4.86	98
DO	3.1	14.72	8.95	0.25	2.44	98
pH	6.84	9.9	8.45	0.058	0.574	98
SD	0.3	1.7	0.70	0.053	0.525	97
TP	0.02	0.62	0.08	0.070	0.070	97
DIP	0.006	0.18	0.01	0.002	0.020	97
TN	0.35	3.5	1.00	0.043	0.427	97
NO_3N	0.008	0.84	**0.08**	0.013	0.127	97
NH_3N	0.003	1.84	0.13	0.024	0.233	97
Chl-a	0.267	92.0	18.0	2.00	20.0	97
SS	1.8	129	19.0	2.23	21.0	86
Valid N (listwise)						86

Table 3. Descriptive statistics of surface water quality of Lake Hwajinpo from 2013-2015.

Parameters	Minimum	Maximum	Mean	Standard Error	Standard deviation	Observations
Temp	9.1	28.7	**20.6**	0.7	5.3	59
Cond	11840	29079	18491	697	5351	59
Sal	5.2	17.6	11.3	0.4	3.2	59
DO	5.4	12.1	8.6	0.2	1.7	59
pH	6.7	9.7	8.1	0.2	1.2	59
SD	0.4	1.6	0.80	0.01	0.3	59
TP	0.020	0.110	0.057	0.003	0.022	59
DIP	0.001	0.020	0.006	0.001	0.006	59
TN	0.404	2.190	0.823	0.038	0.295	59
NO_3N	0.006	0.390	0.056	0.014	0.109	59
NH_3N	0.001	1.130	0.130	0.027	0.207	59
Chl-a	7.15	45.20	20	1.57	12.06	59
SS	6	119	**27**	3	20	59
Valid N (listwise)						59

in the latter period as well. The highest mean values of nutrient components TP, DIP and TN were 0.093 mg/L, 0.017 mg/L and 1.235 mg/L, respectively. Chl-a had the highest mean value 37 mg/m^3 in 1998-2003 and the lowest mean value 19 mg/m^3 in 2004-2009.

3.2. Relations between Water Quality Parameters

Spearman's rank correlation coefficients matrices of water variables for three periods are presented in **Tables 4-6**. Overall, correlation coefficients values (p <

Table 4. Spearman's rank correlation and p-value of water quality variables in Hwajinpo from 1998-2003.

Parameters	Cond	Sal	DO	pH	SD	TP	DIP	TN	NO_3N	NH_3N	Chl-a	SS
Temp	−0.08	−0.07	−0.235*	0.06	−0.08	0.306**	0.07	0.19	0.320**	−0.17	0.279**	−0.01
Cond		0.998**	−0.18	0.12	0.06	−0.05	−0.224*	0.12	−0.372**	−0.330**	−0.19	0.265*
Sal			−0.19	0.11	0.07	−0.05	−0.218*	0.11	−0.360**	−0.329**	−0.200*	0.275*
DO				0.510**	−0.13	0.03	0.08	0.263**	0.14	0.15	0.16	0.00
pH					−0.13	0.225*	0.00	0.279**	0.10	−0.10	0.17	0.12
SD						−0.366**	0.248*	−.348**	−0.04	0.09	−0.351**	−0.341**
TP							0.206*	0.548**	0.02	−0.08	0.453**	0.353**
DIP								0.233*	0.07	0.250*	−0.251*	0.06
TN									0.19	0.01	0.327**	0.17
NO_3N										0.10	0.07	−0.03
NH_3N											0.14	−0.07
Chl-a												0.18

Significance level (α) = 0.05, two-tailed. *p < 0.01 and **p < 0.05, p > |r| under H0:Rho = 0.

Table 5. Spearman's rank correlation and p-value of water quality variables in Hwajinpo from 2004-2009.

Parameters	Cond	Sal	DO	pH	SD	TP	DIP	TN	NO_3N	NH_3N	Chl-a	SS
Temp	−0.08	−0.071	−0.235*	0.06	−0.082	0.306**	0.065	0.192	0.320**	−0.166	0.279**	−0.009
Cond		0.998**	−0.181	0.116	0.064	−0.053	−0.224*	0.116	−0.372**	−0.330**	−0.185	0.265*
Sal			−0.191	0.108	0.068	−0.052	−0.218*	0.109	−0.360**	−0.329**	−0.200*	0.275*
DO				0.510**	−0.126	0.029	0.083	0.263**	0.136	0.153	0.157	0.003
pH					−0.129	0.225*	0.002	0.279**	0.097	−0.1	0.165	0.115
SD						−0.366**	0.248*	−0.348**	−0.036	0.085	−0.351**	−0.341**
TP							0.206*	0.548**	0.021	−0.078	0.453**	0.353**
DIP								0.233*	0.067	0.250*	−0.251*	0.059
TN									0.192	0.008	.327**	0.167
NO_3N										0.103	0.071	−0.027
NH_3N											0.14	−0.072
Chl-a												0.181

Table 6. Spearman's rank correlation and p-value of water quality variables in Hwajinpo from 2013-2015.

Parameters	Cond	Sal	DO	pH	SD	TP	DIP	TN	NO_3N	NH_3N	Chl-a	SS
Temp	0.381**	0.195	−0.720**	−0.004	−0.214	0.279*	0.142	−0.273*	0.047	0.091	−0.194	−0.194
Cond		0.865**	−0.255	0.037	−0.21	0.144	−0.104	−0.485**	−0.372**	0.339**	−0.269*	0.057
Sal			−0.153	−0.104	−0.321*	0.061	−0.133	−0.481**	−0.492**	0.337**	−0.297*	0.114
DO				0.248	0.079	−0.352**	−0.247	0.203	−0.028	0.112	0.082	0.206
pH					−0.275*	0.215	−0.567**	0.382**	0.457**	−0.148	0.204	0.137
SD						−0.511**	0.334**	−0.009	0.046	0.069	−0.315*	−0.243
TP							−0.124	0.285*	0.224	−0.171	0.649**	0.04
DIP								−0.111	−0.195	0.231	−0.14	−0.471**
TN									0.595**	−0.159	0.350**	−0.19
NO_3N										−0.304*	0.295*	−0.001
NH_3N											−0.302*	−0.028
Chl-a												0.214

0.05, two-tailed, in bold) were not very high; however, salinity and conductivity demonstrated highly significant positive correlation for all three periods. DO showed highly significant negative correlation with temperature with the highest coefficient 0.72 in 2013-2015. DO showed significant positive correlation with pH with coefficient values nearly 0.50 in the first two periods. SS correlation with TP and TN were positive and Chl-a and SS were negative. These correlation coefficients were in the range of 0.30 - 0.50. TP was positively correlated with TN with all three periods with coefficients approximately 0.50. TP showed significant correlations with SS in the first two periods but no correlation in 2013-2015. Chl-a demonstrated significant positive correlation with TP and the highest coefficient values was 0.649 in 2013-2015. Similarly, Chl-a showed positive correlation with TN and the values were approximately 0.32. The positive correlations of SS with nutrient components and Chl-a might be related to the discharges of pollutants in lagoon from natural and anthropogenic sources [23] [26].

3.3. Identification of Significantly Important Variables Affecting Water Quality

PCA procedure was applied on each datasets to deduct important variables for each factor. The factors with Eigen value more than 1 (scree plots, **Figure 4**, **Figure 5** and **Figure 6**) were retracted PCA produced six components/factors (**Figure 4**) of the first period (1998-2003) which explained 74.07% of total variance. The first three factors explained nearly 50% of the total variance (20.77%, 16.96% and 11.01% for F1, F2 and F3, respectively). F1 showed the highest positive correlation with Cond and salinity as 0.983 and 0.981, respectively. F2 was

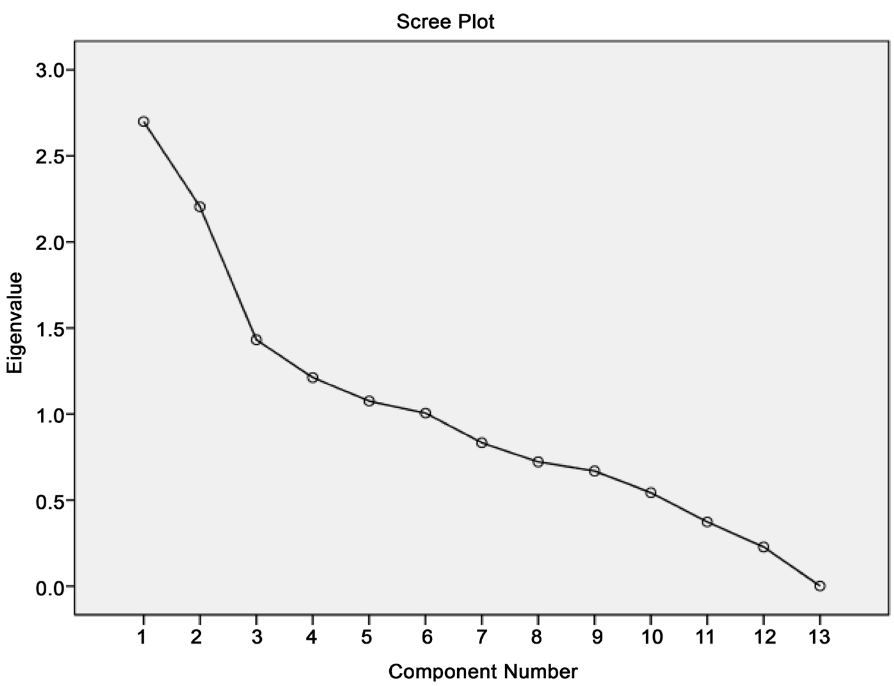

Figure 4. Scree plot (1998-2003).

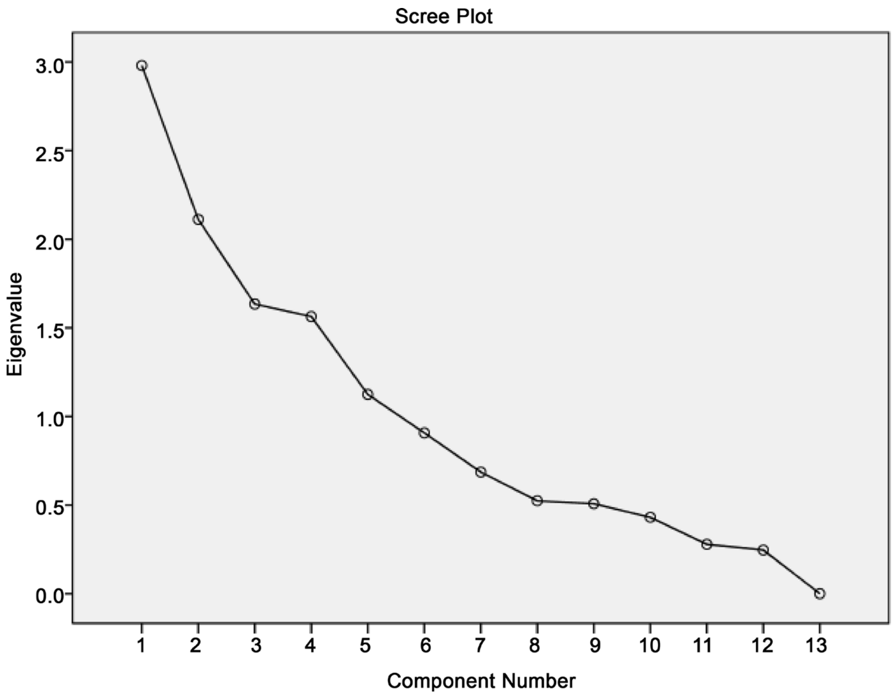

Figure 5. Sree plot of 2004-2009.

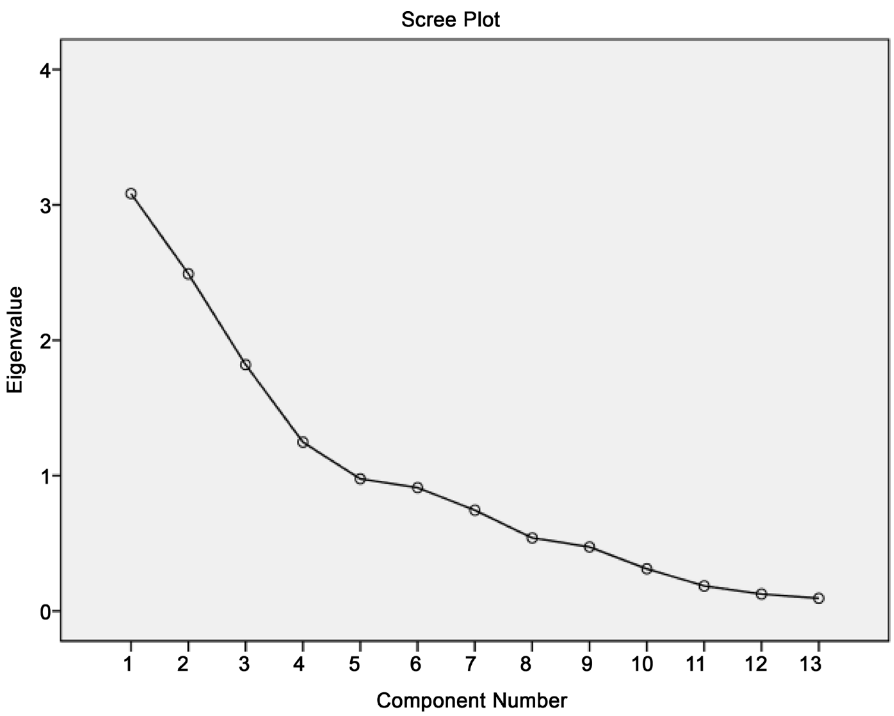

Figure 6. Scree plot of 2013-2015.

positively correlated with TN and Chl-a and negatively correlated with SD. Third factor showed positive correlation with Temp and TP and negative correlation with SS. F4, F5 and F6 showed positive correlation pH and NH_3-N, DIP and SS and DO, respectively (Table 7). The first factor of 2004-2009 data explained 22.93% of the total variance and largely and positively contributed by

Table 7. Rotated component matrix (a) of Lake Hwajinpo from1998-2003.

	Factor(F)s					
Parameters	1	2	3	4	5	6
Temp	−0.085	0.092	**0.746**	−0.171	0.155	−0.030
Cond	**0.930**	0.027	−0.071	−0.147	0.007	−0.139
Sal	**0.929**	0.027	−0.067	−0.132	−0.003	−0.144
DO	−0.048	−0.035	−0.006	−0.081	−0.035	**0.926**
pH	−0.132	0.035	−0.226	**0.774**	−0.039	0.080
SD	0.238	**−0.675**	0.070	0.097	−0.047	0.129
TP	0.163	0.325	**0.679**	0.246	0.182	0.091
DIP	0.044	−0.016	0.243	0.041	**0.905**	−0.059
TN	0.316	**0.770**	0.224	0.165	0.035	−0.185
NO_3N	**−0.669**	0.014	−0.057	−0.052	−0.133	−0.231
NH_3N	−0.055	−0.042	0.278	**0.690**	0.055	−0.213
Chl-a	0.053	**0.850**	0.128	−0.018	−0.017	0.217
SS	0.241	0.235	**−0.603**	−0.117	**0.538**	0.079
Variance explained by each factor						
Factors	1	2	3	4	5	6
% of Variance	20.77	16.96	11.01	9.33	8.28	7.74
Total variance explained %						74.07

Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser Normalization. a: Rotation converged in 6 iterations.

Cond and salinity. F2 explained 16.23% of the total variance and positively correlated with Temp, TP and Chl-a and negatively correlated with SD. F3 was correlated positively with DO and pH. F4 and explained 12.03% and 8.65% of the total variance and positively contributed by TN and NH_3N and DIP and SS, respectively. The total variance explained was 72.42% (**Table 8**). Factor results of 2013-2015 data were presented in **Table 9** where total variance explained was 66.46% by four factors. The first factor explained 23.72% of the total variance. F1 showed positive correlations with TP (0.887) and Chl-a (0.788) and negative correlations with SD (0.667). F2 was positively contributed by DO and NO_3N and negatively contributed by DIP. F3 explained 13.99% of the total variance and heavily contributed by Cond and salinity. TN and NH_3N were the main parameters correlated with F4 with positive coefficients.

3.4. Discussion

Lake Hwajinpo water quality demonstrated in this study showed wide variations in three periods in 1998-2015. The mean temperature decreased in the second period and increased in the third period (2013-205) with the highest (in bold) temperature 20.6˚C. Lagoon surface water temperature is an important factor to

Table 8. Rotated component matrix (a) of Hwajinpo from 2004-2009.

Parameters	Factors				
	1	2	3	4	5
Temp	−0.096	**0.726**	−0.25	−0.151	−0.264
Cond	**0.983**	−0.054	−0.012	−0.030	0.009
Sal	**0.981**	−0.056	−0.019	−0.038	0.009
DO	−0.172	0.045	**0.825**	0.204	0.009
pH	0.092	0.186	**0.812**	−0.023	−0.052
SD	−0.002	−0.583	−0.191	0.071	−0.295
TP	−0.078	**0.706**	0.184	0.245	0.278
DIP	−0.154	0.023	−0.223	0.134	0.734
TN	0.164	0.367	0.122	**0.805**	0.021
NO_3N	−0.388	0.182	0.203	0.422	0.228
NH_3N	−0.203	−0.347	0.022	**0.806**	−0.043
Chl-a	−0.088	**0.668**	0.385	0.145	−0.165
SS	0.122	0.034	0.112	−0.079	**0.878**
Variance explained by each factor					
Factors	1	2	3	4	5
% of Variance	22.93	16.25	12.57	12.03	8.65
%Total variance explained				72.42	

Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser Normalization. a: Rotation converged in 5 iterations.

Table 9. Rotated component matrix (a) of Hwajinpo from 2013-2015.

Parameters	Factors			
	1	2	3	4
Temp	−0.090	−0.756	0.238	0.146
Cond	0.002	−0.176	0.847	0.113
Sal	0.041	−0.119	0.893	−0.037
DO	−0.191	**0.833**	−0.026	−0.043
pH	0.411	0.236	0.134	0.305
SD	**−0.667**	0.126	−0.239	0.062
TP	**0.887**	−0.206	0.009	0.195
DIP	−0.476	−0.577	−0.160	0.009
TN	0.228	0.233	−0.388	**0.781**
NO_3N	−0.061	0.594	−0.440	0.305
NH_3N	−0.06	−0.275	0.174	**0.787**
Chl-a	**0.788**	0.224	−0.272	−0.11
SS	0.23	0.246	0.419	−0.278
Variance explained by each factor				
Factors	1	2	3	4
% of Variance	23.72	19.16	13.99	9.59
%Total variance explained				66.46

Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser Normalization. a: Rotation converged in 5 iterations.

run physicochemical and biological processes in water [27]. Similarly, suspended solids mean value was significantly higher in this period than the previous period with the highest value 27 mg/l. The continuous increase in SS indicates that the construction and agricultural activities in the basin are increasing. The monsoon stormwater runoff causes soil erosion from non-point sources can increase the SS concentration in water body [10] [28]. The decrease in Chl-a was observed in comparing to the first period (1998-2003) in the third period but wa higher than the second period (2004-2009). Water transparency was slightly improved throughout the monitoring periods. Salinity of lagoon plays an important role which varies with inflow of freshwater from streams and runoff, and circulation to the sea water. The salinity in Lake Hwajipo was the lowest in the third period. This could be related to the low water circulation between North and South due to the narrow connecting channel [16]. The nutrient (N and P) components were slightly lower in the third period of the study as well as SD. The nutrients in the water bodies are the byproduct of the human activities in the basin which have a large localized effect on water chemistry. Land use plays significant role on the hydrology system of the water body and its water quality [2]. DO in water depends on water circulation and photosynthesis activities by phytoplankton in lagoon.

Principal component analysis in this study helped to identify which components/factors were influencing the water quality in different periods. In the first two periods, 1998-2003 and 2004-2005, F1 was mainly contributed by Cond and salinity. These two parameters are related to the physical source variabily. TN and Chl-a in first period and TP, Temp and Chl-a in the second period were the F2 contributing variables. But in the third period TP and Chl-a showed the highest correlation with first factor and contributed 23.72% of the total variance. The sources of TP and TN can be interpreted as point sources (domestic, industrial wastewater etc.) and non-point sources (forests agricultural land etc.) [21]. Sedimentation of nutrients and their release due to suspension and re-suspension also plays important role [29] [30]. Internal and external loading of nutrients are the big factors to be considered to achieve the sustainable water environment of the lagoon. Reclamation of water body through dredging and enhancing water circulation could be the long term goals [31] [32] [33].

In this study, the water quality of Lake Hwajinpo in three different time periods was demonstrated by analyzing physicochemical parameters statistically. And the results showed that the lagoon water quality was distinctly different in each period. The highly significant parameters in the first period (1998-2003) and second period (2004-20090 were less significant in the third period (2013-2015). Total phosphorus and chlorophyll-a were the two water quality parameters highly significant in the third period.

4. Conclusions

Long-term water quality data was analyzed to understand how the physicochemical water quality varied throughout 1998-2015 in Lake Hwajinpo, Korea. The descriptive statistics of the three periods suggested that there was no clear pattern of variation of the water quality parameters. Temperature and suspended solids showed the highest mean values in the third period (2013-2015). Meanwhile, second period (2004-2005) observed the highest mean values of conductivity and salinity. And first period (1998-2003) showed the highest mean values of chlorophyll-a, nutrients etc. Similarly, the PCA/FA results demonstrated no clear pattern of the most important water quality parameters. PCA method explained about 70% variations of each data. Factors deducted in this process, suggested that the total phosphorus and Chlorophyll-a were the most significant parameters in 2013-2015 with 23.72% total variance. And the other parameters were dissolved oxygen and nitrate nitrogen in F2 with 19.16% and conductivity and salinity in F3 with 13.99% total variance. In contrast, conductivity and salinity were the most significant variables in F1 (22.93% of total variance) in 1998-2003 and F1 (20.77% of total variance) in 2004-2009.

Therefore, continuous monitoring of water quality and data analyses are required to understand the water quality status of water bodies. This study will be helpful to water managers and administrator to formulate plan to achieve healthy water through sustainable management.

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