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Characteristics of the Seawater Quality Variation on the South Coastal Area of Korea

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Abstract

Classifying the stations with the similar seawater quality variation, it is possible to cope effectively with and to predict the seawater quality variation on the coastal area. Factor Analysis among various statistical analyses can be used in order to suggest a solution for the above mentioned purposes. And the consequence of factor analysis should be compared and discussed with the relation to the tidal current because seawater quality variance is influenced by the tide. The data for this research was collected from the fifteen stations ranging from Tukryang Bay to Ulsan Bay on the South Costal Area of Korea.. The study was based on the data from 1991 to 2000. The eight seawater quality items analyzed were Water Temperature, Salinity, pH, DO, COD, T-N (Total Nitrogen), T-P (Total Phosphorus), and SS (Suspended Solid). The result of the study will be the following consequences. DO, pH, and SS items showed that fifteen stations were grouped into three or four seawater zones by the axis of Samchonpo~Chinju Bay~South of Koje. On the analysis of all of the eight seawater quality items, the stations of Tukryang Bay and Kohung; and those of Onsan and Ulsan Bay were classified into the same group, respectively. Yosu and Namhae stations were sectioned into one group on the all seawater quality items but T-P, Samchonpo and South of Koje stations another group on all seawater quality items but Water Temperature, and Masan and Pusan stations the other group on all seawater quality items but DO. The stations from Tukryang Bay through Kohung to East of Koje were grouped together on the COD item, and this showed somewhat different tendency among other seawater quality items.

Keywords: *south coastal area of Korea, factor analysis, seawater quality variation, tidal current*

1. Introduction

Researches on the changeability of river water quality using multivariate analysis have been in full flourish home and abroad (Lee *et al.*, 1998 ; Noto *et al.*, 1983 ; Oka *et al.*, 1983 ; Park *et al.*, 1991 ; Wada *et al.*, 1987) but those on the changeability of seawater quality on the coastal area leave something to be desired.

The factors influencing on the seawater quality variation are

i) various influx points to the coastal area of non-point sources
ii) the morphological characteristics of the coast
iii) vertical movement of water mass by water temperature and the density
iv) the circumstances of fishing grounds
v) tidal current and ocean current
vi) wind, etc

so diverse in comparison with the river water that it is not easy to apply statical analysis and interpretation to this case.

By reason of various influences and quality their complicated interaction, we remain on the level of reducing the red tide, which occurs more frequently than ever on a yearly basis, rather than predicting its occurrence. To reduce the frequent occurrence of a red tide and to cope effectively with it, it is necessary to control the seawater quality by sectioning the areas of the waters showing similar variation characteristics on the seawater quality items into the same seawater zone.

Among various statistical analyses, Factor Analysis on the seawater data of the past several years will be of help to control seawater zones (i.e., controlling and managing waters by sectioning the areas of the seawater showing similar variation characteristics on the seawater quality items

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into the same seawater zone). The results of Factor Analysis contribute not only to the above mentioned purpose but also to reducing the number of stations when Regression Analysis is drawn on between the weather factor and the water quality factors. In addition, it will be of some help to predict that the seawater quality variation at a certain station is correlated with that at the other stations within the same seawater zone which share similar variation characteristics.

This study employed the seawater quality data which were collected from the fifteen stations on the South Coastal Area and the data were gathered in the months of February, May, August, and November. And the seawater quality items analyzed were eight items in all; Water Temperature (°C), Salinity(‰), pH, DO(mg/L), COD(mg/L), Total Nitrogen (T-N)(mg/L), Total Phosphorus (T-P)(mg/L), and Suspended Solid (SS)(mg/L).

2. Basic Theory(Alexander, 1994 ; Kim and Jeon, 1997)

The observable random vector X, with p components, has mean μ and covariance matrix Σ. The factor model postulates that X is linearly dependent on a few unobservable random variables $F_1, F_2, \ldots, F_m$. The variables are called common factors. The p additional sources of variation $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_p$ are called errors or specific factors. In particular, the factor analysis model may be expressed as follows.

$$\begin{aligned} X_1-\mu_1 &= l_{11}F_1+l_{12}F_2+l_{13}F_3+\ldots+l_{1m}F_m+\varepsilon_1 \\ X_2-\mu_2 &= l_{21}F_1+l_{22}F_2+l_{23}F_3+\ldots+l_{2m}F_m+\varepsilon_2 \\ &\vdots \\ X_p-\mu_p &= l_{p1}F_1+l_{p2}F_2+l_{p3}F_3+\ldots+l_{pm}F_m+\varepsilon_p \end{aligned} \quad (1)$$

The above equation is as follows.

$$\underset{(p\times 1)}{X}-\underset{(p\times 1)}{\mu}=\underset{(p\times m)}{L}\times \underset{(m\times 1)}{F}+\underset{(p\times 1)}{\varepsilon} \quad (2)$$

The coefficient l_{ij} is called the loading of the ith variable on the ith factor. The matrix L is the matrix of the factor loadings. Note that the ith specific factor is also associated only with the ith response X_i. The p deviations $X_1-\mu_1$, $X_2-\mu_2 \ldots X_p-\mu_p$ are expressed in terms of $p+m$ random variables $F_1, F_2, \ldots, F_m, \varepsilon_1, \varepsilon_2, \ldots, \varepsilon_p$ which are unobservable. Covariance structure for the orthogonal factor model which may be expressed as follows.

$$Cov(X) = LL' + \Psi \quad (3)$$

$$Var(X_i) = \sigma_{ii} = h_i^2 + \Psi_i \quad (4)$$

In Equation (4), h_i^2 is defined as

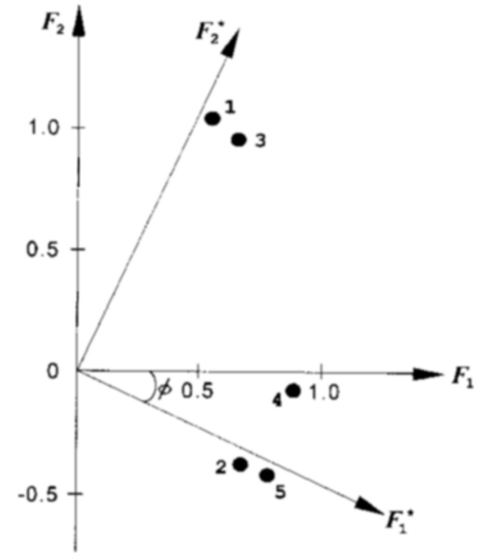

Fig. 1. Factor Rotation

$$h_i^2 = l_{i1}^2 + l_{i2}^2 + \ldots + l_{iq}^2 \quad (5)$$

$$Cov(X_i, X_k) = l_{i1}l_{k1} + l_{i2}l_{k2} + \ldots + l_{im}l_{km} \quad (6)$$

$$Cov(X, F) = L \quad (7)$$

$$\text{or } Cov(X_i, F_j) = l_{ij} \quad (8)$$

In Equation (4), h_i^2 is the ith communality and it means the sum of squares of the loadings of the ith variable on the m common factor. Covariance for X may be reproduced from the pm factor loadings l_{ij} and the p specific variance Ψ_i.

If we try to interpret the meaning of factors by the properties of the loading value l_{ij} after obtaining the factor matrix scoring the factor loading of each variable, it may be hard to make out the meaning of the first gained factors which were unrotated. Therefore, it needs to rotate the axis of the factors in order to make it represent its obvious characteristics. The orthogonal and the oblique solutions were used as a method of rotating factors.

If $\tilde{L}^*$ is postulated to a matrix containing $p\times m$, then the following formula (9) becomes valid.

$$\tilde{L}^* = \tilde{L}T \quad (9)$$

Where, $\tilde{L}^*$ is a rotated factor loading, $TT' = T'T = I$, T is the orthogonal matrix of $m\times m$, T' is the inverse matrix of T, and I is the unit matrix.

Fig. 1 represents the result of rotated coordinate axis in a rotating angle ϕ, and the numbers 1~5 are the factor loading of each variable.

F_1 and F_2 represent unrotated factors, F_1^* and F_2^* and are rotated factors in a rotating angle .

3. Analyses and Evaluation

The collected data on seawater quality from fifteen South Coastal stations including Kohung were analyzed by the analytical method of Factor Analysis with SAS (Statistical Analysis System) 6.11 running on IBM PC platform. The study was based on the data from 1991 to 2000. The eight seawater quality items analyzed were Water Temperature, Salinity, pH, DO, COD, T-N, T-P, and SS. Some of the data from 1991 to 1994 were quoted from the statistical yearbook published by Ministry of Environment (Ministry of Environment,1990-1996), others from 1995 to 2000 were cited from the homepage of National Fisheries Research and Development Institute (http://www.nfrda.re.kr/sitemap/technic/environment_1.htm, 1996-2000). The Romanization of the survey stations refer to the 1995 statistical yearbook published by Ministry of Environment.

Fifteen stations surveyed are illustrated in Fig. 2, 3 and 4 in which the place names are shown in Table 1(a) and 1(b).

Fig. 2. Flood Current

Fig. 3. Ebb Current

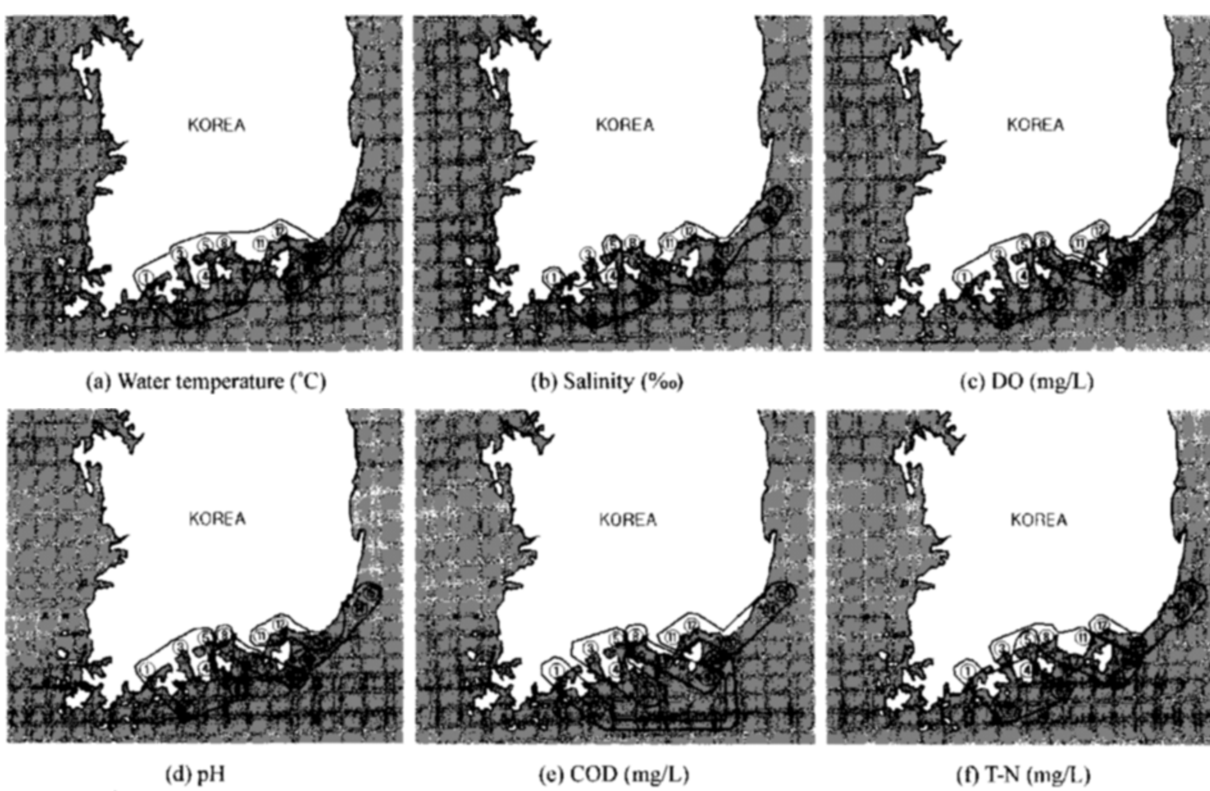

Fig. 4. Illustration of Factor Analysis

Table 1(a). Statistical Characteristics(from Tukryang Bay to Samchonpo Station)

Items	Sta. Val.*	Tukryang Bay 1	Kohung 2	Yoja Bay 3	Yosu 4	Kwangyang Bay 5	Namhae 6	Samchonpo 7
Water Temperature (°C)	Max	28.000	28.000	30.000	31.000	31.000	32.000	28.000
	Min	5.275	1.000	4.233	2.000	3.000	3.000	6.133
	Mean.	16.581	16.282	16.668	16.127	16.955	16.665	16.391
	Std. Dev.	6.958	6.934	7.462	7.318	7.699	6.900	6.257
Salinity (‰)	Max.	33.705	33.920	34.100	34.500	34.700	40.824	36.800
	Min.	20.700	20.400	22.000	23.400	22.840	24.000	23.700
	Mean.	30.003	30.073	29.147	29.732	29.225	30.681	32.115
	Std. Dev.	2.581	2.765	2.641	2.827	2.912	3.301	2.550
pH	Max.	8.373	8.344	8.357	8.566	8.400	8.600	8.522
	Min.	6.900	7.000	6.900	7.600	7.700	7.700	7.800
	Mean.	8.010	8.015	7.990	8.091	8.119	8.108	8.136
	Std. Dev.	0.254	0.225	0.274	0.184	0.169	0.170	0.147
DO (mg/L)	Max.	11.930	11.511	13.300	11.510	12.100	11.500	11.900
	Min.	6.383	5.878	5.898	4.675	5.860	4.906	4.973
	Mean.	8.883	8.689	8.728	8.733	8.818	8.563	8.201
	Std. Dev.	1.340	1.359	1.676	1.716	1.745	1.759	1.377
COD (mg/L)	Max.	2.413	2.200	3.418	3.408	3.493	3.040	2.708
	Min.	0.690	0.708	0.578	0.981	1.197	0.294	0.458
	Mean.	1.498	1.387	1.696	1.563	2.118	1.262	1.389
	Std. Dev.	0.340	0.312	0.528	0.450	0.422	0.410	0.459
T-N (mg/L)	Max.	0.422	0.405	0.421	0.712	0.786	0.456	1.491
	Min.	0.014	0.017	0.011	0.014	0.015	0.016	0.016
	Mean.	0.159	0.151	0.187	0.187	0.224	0.143	0.502
	Std. Dev.	0.112	0.097	0.113	0.117	0.135	0.092	0.438
T-P (mg/L)	Max.	0.077	0.052	0.092	0.079	4.657	0.034	0.045
	Min.	0.000	0.003	0.002	0.004	0.009	0.001	0.000
	Mean.	0.014	0.014	0.021	0.029	0.211	0.016	0.015
	Std. Dev.	0.014	0.009	0.020	0.018	0.800	0.008	0.011
SS (mg/L)	Max.	30.500	45.433	44.400	21.175	39.767	24.125	27.567
	Min.	1.600	2.000	4.067	2.400	3.000	2.300	1.600
	Mean.	9.788	11.552	15.922	8.908	12.536	7.028	6.784
	Std. Dev.	6.012	6.937	8.566	4.619	6.933	4.380	4.814

*Statistical Values
**Maximum Values
***Minimum Values
****Mean Values
*****Standard Deviation

3.1 Tidal Current

The tides producing the ocean currents can be classified into semidiurnal tides, diurnal tides, and mixed tides. The south coastal area yields the diurnal tides and the east coastal area causes the mixed tides. The semidiurnal tides create a flood current and an ebb current approximately once every 12 hours. And the mixed tides generate a high tide and a low tide once a day when the diurnal inequality is

Table 1(b). Statistical Characters(from Chinju Bay to Ulsan Station)

Items	Sta. Val.	Chinju Bay 8	South of Koje 9	East of Koje 10	Chinhae Bay 11	Masan Bay 12	Pusan 13	Onsan 14	Ulsan 15
Water Temperature (℃)	Max.**	28.000	28.000	28.000	29.000	29.000	25.000	26.000	26.000
	Min.***	5.750	5.000	5.000	5.000	5.000	8.000	5.000	5.000
	Mean.****	16.242	16.526	16.623	16.085	16.501	16.224	16.173	16.279
	Std. Dev.*****	6.474	5.435	5.160	6.521	6.750	4.553	4.707	4.659
Salinity (‰)	Max.	35.600	35.300	35.300	35.500	39.200	35.200	34.800	34.800
	Min.	17.090	28.790	29.000	24.075	21.355	28.200	27.000	28.300
	Mean.	31.172	32.578	32.804	31.757	30.316	32.653	32.701	32.634
	Std. Dev.	3.856	1.749	1.734	2.519	3.491	1.917	1.981	1.779
pH	Max.	8.545	8.400	8.460	8.900	9.100	8.477	8.595	8.555
	Min.	7.590	7.800	7.800	7.235	7.795	7.712	7.700	7.200
	Mean.	8.102	8.144	8.169	8.218	8.294	8.168	8.156	8.088
	Std. Dev.	0.188	0.160	0.173	0.252	0.295	0.165	0.167	0.239
DO (mg/L)	Max.	11.600	10.325	10.500	12.700	15.900	10.200	12.500	10.600
	Min.	5.080	5.508	6.158	3.975	4.180	6.013	5.970	6.129
	Mean.	8.055	8.093	8.177	8.447	8.420	7.909	8.508	8.263
	Std. Dev.	1.510	1.048	0.910	1.886	2.628	0.879	1.148	0.957
COD (mg/L)	Max.	3.305	3.000	3.000	3.400	8.100	2.800	2.900	2.820
	Min.	0.795	0.571	0.703	1.075	0.800	1.000	0.900	1.175
	Mean.	1.453	1.210	1.278	2.027	3.834	1.745	1.810	1.799
	Std. Dev.	0.507	0.460	0.454	0.551	1.580	0.467	0.575	0.352
T-N (mg/L)	Max.	1.476	1.262	1.262	1.633	2.543	1.734	2.724	2.111
	Min.	0.029	0.047	0.033	0.042	0.123	0.084	0.070	0.098
	Mean.	0.596	0.490	0.520	0.644	1.019	0.723	0.857	0.959
	Std. Dev.	0.446	0.398	0.376	0.477	0.534	0.460	0.629	0.486
T-P (mg/L)	Max.	0.075	0.035	0.060	0.097	0.257	0.106	0.195	0.101
	Min.	0.003	0.000	0.000	0.005	0.010	0.004	0.001	0.004
	Mean.	0.020	0.013	0.014	0.025	0.066	0.032	0.025	0.024
	Std. Dev.	0.015	0.010	0.013	0.027	0.054	0.023	0.036	0.021
SS (mg/L)	Max.	20.300	15.625	13.750	30.600	20.000	14.933	19.100	17.700
	Min.	1.500	0.950	1.400	1.000	1.800	1.500	0.900	1.375
	Mean.	8.687	5.273	4.871	5.543	7.379	6.739	5.558	6.649
	Std. Dev.	5.004	3.352	2.923	4.796	3.866	3.646	3.341	3.536

*Statistical Values
**Maximum Values
***Minimum Values
****Mean Values
*****Standard Deviation

large enough (Lee. S.R *et al.*, 2002).

Pollutants in the closed sea are transferred offshore quickly by the tidal currents and influence on the seawater quality variation of the adjoining sea zone. Accordingly, we investigated the relation between the consequence of the factor analysis and the tidal currents using Tidal Current Chart published by National Oceanographic Research Institute which is affiliated to Ministry of Maritime Affairs and

Table 2. Maximum and Minimum Values

Items	Maximum Value				Minimum Value			
	Value	Station	Year	Month	Value	Station	Year	Month
Water Temperature (℃)	32.000	Namhae	1992	8	1.000	Kohung	1991	2
Salinity (‰)	40.824	Namhae	1997	2	17.090	Chinju Bay	1999	8
pH	9.100	Masan Bay	1994	8	6.900	Tukryang Bay, Yoja Bay	1991	11
DO(mg/L)	15.90	Masan Bay	1996	5	3.975	Chinhae Bay	1997	8
COD(mg/L)	8.100	Masan Bay	1994	5	0.294	Namhae	2000	2
T-N(mg/L)	2.724	Onsan	1995	8	0.011	Yoja Bay	2000	2
T-P(mg/L)	4.657	Kwangyang Bay	1991	2	0.000	Samchonpo	1991	2,5, 8,11
SS(mg/L)	45.433	Kohung	1997	2	0.900	Onsan	1999	8

Table 3. Partial Correlation

Symbols of Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		B,D, F,G	A,D							G					
2				G,H		F						G			
3					F,H										
4					B,C,E, F,H	A, D							C		
5						D		B							
6														H	
7								A,B,C, D,G,H	C,H		B,H		B,G		
8		G										B,G		G	B
9	G	H								A,B,C,D, E,G,H					
10															D
11								B				A,B,C			
12							B						B		G
13			B		C			B,G						G	B
14							G				C				A,C,D, F,G
15							B					B			

Fisheries.

The flood and ebb currents are illustrated in Fig. 2 and 3 (Ministry of Maritime Affairs and Fisheries, Mar. 1999, Dec. 1999, Mar. 2001, Nov. 2001, Sep. 2002, Dec. 2002). The flood current (Fig. 2) flows from Busan through Mokpo to Incheon, whereas the ebb current (Fig. 3) shows the reverse flow. In the case of the flood current, inshore currents were observed; while the ebb current showed offshore currents. But Onsan and Ulsan stations which have been under the influence of the mixed tides showed no regular currents.

3.2 Statistical Description

Basic statistical description is shown in Table 1 (Smith, 1986).

The stations, the months, and the years showing maximum and minimum values in Table 1(a) and (b) are represented in Table 2.

Focusing on the frequency of maximum and minimum values, as shown in Table 2, we can find that the high fre-

Table 4. Symbols of Water Quality

Items	Water Temperature (°C)	Salinity (‰)	DO (mg/L)	pH	COD (mg/L)	T-N (mg/L)	T-P (mg/L)	SS (mg/L)
Symbols	A	B	C	D	E	F	G	H
Positive Correlation / Negative Correlation	6/0	12/6	7/2	8/0	2/0	5/0	12/4	8/1

quency of maximum value was marked at Namhae and Masan Bay stations.

3.3 Partial Correlation Analysis

Partial correlation coefficient was calculated so as to analyze the true correlation of the only two stations for each water quality item (Lee *et al.*, 1998 ; Richard and Dean, 1992).

The seawater quality items scoring interstation partial correlation coefficient over 0.5 were described in Table 3, in which the place names are shown in Table 1(a) and 1(b). The symbols used in Table 3 were indicated in Table 4. The right side of the double full line is indicative of positively correlated stations, and the left side means negatively correlated ones in Table 3.

In Table 3, the stations Tukryang Bay~Kohung, Yosu~Kwangyang Bay, Samchonpo~Chinju Bay, South of Koje~East of Koje, Chinhae Bay~Masan Bay, and Onsan~Ulsan Bay can be grouped together and they show high interstation correlation. The direct impact of the tidal current might have influence on the high partial correlation between the two stations.

3.4 Factor Analysis

Factor Analysis was performed on the eight seawater quality items inclusive of Water Temperature between stations (Beaudoin and Rousselle,1982). Four factors were set for the common factors. As a result of analysis, MSA (Measure of Sampling Adequacy) scored all over 80% so that the number of factors can be said sufficient enough (Lee and Kim,1997). Factor Rotation used the VARIMAX solution of orthogonal solutions. As a consequence of factor analysis on the seawater quality items, the stations showing similar variational characteristics are grouped together as in Fig. 4.

DO, pH and SS items showed that fifteen stations were grouped into three or four seawater zones by the axis of Samchonpo~Chinju Bay~South of Koje (Fig. 4(c), (d), and (h)). The adjacent stations to the southward or northward but not those to the eastward or westward were classified into the same group.

On the analysis of all of the eight seawater quality items, the stations of Tukryang Bay and Kohung; and those of Onsan and Ulsan Bay were classified into the same group, respectively. Yosu and Namhae stations were sectioned into one group on the all seawater quality items but T-P, Samchonpo and South of Koje stations another group on all seawater quality items but Water Temperature, and Masan and Pusan stations the other group on all seawater quality items but DO. The stations from Tukryang Bay through Kohung to East of Koje were grouped together on the COD item, and this showed somewhat different tendency among other seawater quality items.

3.5. Discussion on the Consequence of Factor Analysis and Tidal Current

When Fig. 2 and 3 are compared with Fig. 4, the changeability of the seawater quality between the bays and the inshore point adjacent to them (namely, the point of a current flowing into the bay) is similar because of the flood and ebb currents.

But further study has to be followed in that

i) Yoja Bay and Chinju Bay are not grouped together with the adjacent stations on the Salinity item (Fig. 4(b)).

ii) East of Koje does not grouped into the same zone with the adjacent station on the COD item (Fig. 4(e)).

iii)Kwangyang Bay is not classified into the same group with the adjacent stations on the T-P and T-N items (Fig. 4(f) and 4(g)).

4. Conclusions

In order to classify the stations showing similar characteristics of the seawater quality variation, factor analysis were performed on the eight seawater quality items inclusive of Water Temperature for ten years at the fifteen south coastal stations. As a result of examination into the relation between the result of factor analysis and the tidal current, the following conclusions were drawn.

1. DO, pH and SS items showed that fifteen stations were

grouped into three or four seawater zones by the axis of Samchonpo~Chinju Bay~ South of Koje.

2. On the analysis of all of the eight seawater quality items, the stations of Tukryang Bay and Kohung; and those of Onsan and Ulsan Bay were classified into the same group, respectively.
3. Yosu and Namhae stations were sectioned into one group on the all seawater quality items but T-P, Samchonpo and South of Koje stations another group on all seawater quality items but Water Temperature, and Masan and Pusan stations the other group on all seawater quality items but DO.
4. The stations from Tukryang Bay through Kohung to East of Koje were grouped together on the COD item, and this showed somewhat different tendency among other seawater quality items.

From those conclusions, we can cope effectively with the seawater quality variation by grouping the stations sharing similar seawater quality variation characteristics on seawater quality items into one seawater zone. The seawater showing similar variation characteristics on the seawater quality items are sectioned into the same zone. Controlling seaseawater quality on a zoned basis make it possible to predict and to cope effectively with the seawater quality variation on the coastal area.

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