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THE RELATIONSHIP BETWEEN THE WATER COLOR AND THE TRANSPARENCY IN THE SEAS AROUND KOREA

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ABSTRACT

The distributions of average water color and the transparency in the seas around Korea show two patterns: the one is the East Sea and the South Sea, the other is the Yellow Sea. In the East Sea and the South Sea, the water colors C_E in Forel scales change from green to greenish blue with distance x in miles from the seashore, an average color is bluish green, 3.7 in Forel scales, and the relationship is given by $C_E=5e^{-0.056\sqrt{x}}$; an average transparency is 15 m and the transparency T_E shows following formula with distance x, $T_E=0.9\sqrt{x}+10$. In the Yellow Sea, the water color C_Y changes from green yellow to bluish green with distance, an average color is light green, 5.6 in Forel scales, and the relationship is given by $C_Y=8.5e^{-0.086\sqrt{x}}$; an average transparency is 7 m, the farther it is from the seashore, the deeper transparency T_Y is as following, $T_Y=1.2\sqrt{x}+1$. Along the seashore, the transparency T_Y is only 10% that of the East Sea and the South Sea. The distributions of the water color and the transparency by depth change in values within the continental shelf.

The water color in Forel scales decreases with the distance from the seashore and depth; the transparency increases with the distance and depth. They are caused by suspended particles, especially suspended clay, and it is the major factor in the change in color and transparency, particularly in the Yellow Sea. In September, the sea water is the clearest in the seas around Korea, transparency shows the maximum and water color the minimum in Forel scales. The water color shows green yellow when transparency is 1 m, green at 10 m, and greenish blue at 20 m. The relationship between the water color and the transparency shows an exponential distribution as following,

$$C=9\,e^{-kT},\qquad k=0.0625\,m^{-1}.$$

This formula agrees with calculated formulas between the water color and the transparency from the empirical formulas C_E and T_E, C_Y and T_Y.

INTRODUCTION

The physical relationships governing the penetration and absorption of light, the color of the water, and the transparency of the sea are of prime importance to geophysical and biological oceanography.

The dependence of scattered intensity on the inverse fourth power of wavelength accounts for the color of the sea water; blue light, of shorter wavelength, is scattered more strongly than light of other colors. The blue waters are typical in color of the open oceans, particularly in middle and lower latitudes, whereas the green water is more common in coastal areas(Sverdrup, et al., 1942). The transition from blue to green can not be explained, however, as a result of scattering, and Kalle(1938) concludes that this transition is due to yellow substance, pointing out that the combination of the yellow color and the natural blue of the water leads to a scale of green colors observed in the sea.

The transparency or clarity is related in a complex way to the optical properties of the sea water. In the English Channel, the extinction coefficient of visible rays can be roughly obtained from the formula $\kappa=1.7/T$, where T is the transparency in meters(Poole and Atkins, 1929); and transparency T depends upon water turbidity, $T=40/F$, where F is amount of suspended particles mg/*l*, in the sea water.

The relationship between the water color and the transparency, and their distributions are very important ways to study optical properties of the sea water, so they are studied with previous data.

METHODS AND DATA

The water color and the transparency have been observed by the Forel scales and Secchi disk since 1921 in the seas around Korea. Observation stations are shown in Fig. 1.

Those methods are some rough, but for a long time more than 10 years, they are obsered by same methods, regularly and continuously, six times a month at 5 shore stations and once a month at 78 serial oceanographic stations within 80 miles from the seashore. And these data are used for analysis, shown in Table 1 and Table 2, others for reference.

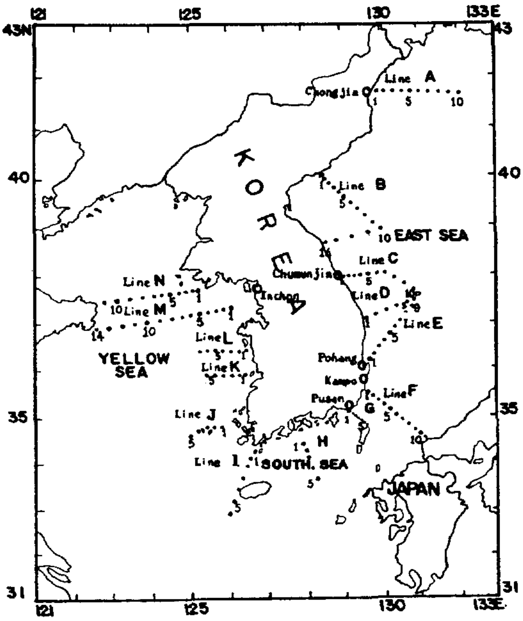


Fig. 1. Location of the observation stations in the seas around Korea.

Table 1. Distributions of the water color and the transparency at shore stations.

Station Name	Location		Water Color (Forel scales)		Transparency (m)		Depth (m)
			Mean	Variation (△)	Mean	Variation (△)	
Chongjin	41°14′N,	130°32′E	4.4	0.28	11.2	1.45	29
Chumunjin	37 50	128 54	4.5	0.20	9.6	0.56	15
Pohang	36 03	129 26	4.0	0.17	10.1	1.15	50
Kampo	35 48	129 31	6.2	0.17	6.5	0.54	11
Pusan	35 05	129 02	7.2	0.24	3.8	0.43	9

Table 2. Distributions of the water color and the transparency at serial oceanographic stations.

Line	Station No.	Location		Water Color (Forel scale)	Transparency (m)	Distance (mile)	Depth (m)
A	1	41°46′N,	129°54′E	4.4	13.1	2	91
A	2	41 46	130 00	4.1	14.7	7	151
A	3	41 46	130 10	4.0	15.7	15	900

A	4	41°45′N,	130°24′E	4.2	16.9	25	2200
A	5	41 45	130 36	3.8	17.3	35	3100
A	6	41 44	130 49	3.4	17.7	45	2900
A	7	41 44	131 02	3.5	17.8	55	2900
B	1	39 58	128 15	4.8	11.3	2	59
B	2	39 55	128 20	4.4	12.5	7	104
B	3	39 50	128 28	3.8	13.2	15	500
B	4	39 44	128 39	3.9	14.2	25	1400
B	5	39 39	128 49	3.6	15.0	35	1600
B	6	39 33	128 59	3.2	15.0	45	1800
B	7	39 27	129 10	3.4	14.9	55	1900
B	8	39 18	129 25	3.2	16.3	65	2000
C	1	37 54	128 53	4.1	12.1	2	61
C	2	37 55	128 59	4.0	14.3	7	500
C	3	37 56	129 09	4.0	14.4	15	1000
C	4	37 57	129 21	4.0	14.6	25	900
C	5	37 58	129 34	3.9	15.1	35	1200
C	6	37 59	129 47	4.1	14.4	45	1400
C	7	38 01	130 00	3.9	14.6	55	1500
E	1	36 08	129 34	4.2	10.4	1	50
E	2	36 16	129 42	4.1	12.9	10	200
E	3	36 24	129 50	4.0	14.4	20	300
E	4	36 31	129 58	3.4	15.9	30	400
E	5	36 39	130 05	3.3	16.5	40	1200
E	6	36 46	130 13	3.3	16.1	50	2000
E	7	36 54	130 22	3.5	16.6	60	2100
E	8	37 02	130 29	3.3	15.5	70	2200
F	1	35 29	129 27	4.3	8.1	1	68
F	2	35 25	129 34	4.0	14.0	8	119
F	3	35 18	129 43	3.5	16.6	18	146
F	4	35 11	129 53	3.2	17.0	28	153
F	5	35 06	130 02	3.1	17.6	38	137
F	6	34 59	130 11	3.1	17.0	48	129
F	7	34 53	130 20	3.1	17.1	58	132
F	8	34 46	130 30	3.0	17.0	68	136
F	9	34 39	130 40	3.0	16.5	78	127
G	1	35 01	129 07	4.9	9.2	2	85
G	2	34 57	129 11	3.8	14.0	7	102
G	3	34 54	129 15	3.3	16.8	12	126
G	4	34 51	129 19	3.0	18.0	17	225
G	5	34 48	129 22	3.1	18.0	20	157
G	6	34 45	129 26	3.3	16.3	25	74
H	1	34 22	127 50	5.0	7.2	2	61
H	2	34 14	127 53	4.2	9.7	10	62
H	3	34 05	127 57	3.8	14.2	20	78
H	4	33 51	128 03	3.5	15.0	35	96
H	5	33 36	128 10	3.4	16.9	50	117
J	1	34 43	125 43	6.8	2.7	6	37

J	2	34°43′N,	125°31′E	6.3	3.6	16	81
J	3	34 43	125 19	5.5	5.7	26	91
J	4	34 40	125 07	4.6	8.1	36	91
J	5	34 35	124 57	4.3	9.8	46	88
K	1	35 51	126 17	7.6	4.0	2	44
K	2	35 51	126 07	6.7	5.8	10	36
K	3	35 51	125 55	5.9	7.3	20	50
K	4	35 51	125 42	5.3	9.2	30	58
K	5	35 51	125 30	4.4	10.8	40	69
K	6	35 51	125 18	4.3	13.0	50	77
L	1	36 20	126 28	6.3	2.2	2	29
L	2	36 20	126 18	6.6	2.5	10	13
L	3	36 20	126 07	5.7	4.8	20	27
L	4	36 20	125 54	4.8	7.5	30	52
L	5	36 20	125 41	4.1	8.4	40	54
L	6	36 20	125 29	3.8	10.8	50	57
L	7	36 20	125 17	3.7	12.0	60	63
M	1	37 10	125 52	8.3	1.4	5	30
M	2	37 09	125 39	8.2	1.7	15	26
M	3	37 08	125 27	6.6	3.0	25	32
M	4	37 07	125 14	5.5	6.0	35	45
M	5	37 06	125 02	4.7	8.7	45	56
M	6	37 05	124 51	5.0	10.7	55	67
M	7	37 04	124 39	3.4	13.0	65	72
N	1	37 41	125 10	8.0	2.7	2	51
N	2	37 40	125 00	7.5	4.1	10	45
N	3	37 38	124 49	6.8	5.8	20	51
N	4	37 37	124 37	5.5	8.7	30	74
N	5	37 35	124 25	5.0	11.2	40	78
N	6	37 34	124 13	4.8	11.3	50	75
N	7	37 32	124 00	5.1	11.3	60	73
N	8	37 30	123 42	4.9	11.7	70	73

The previous data are put following various reports together; results of the coastal observations (Fisheries Experiment Station, 1926, 1928-1942), results of the serial oceanographic observations (Fisheries Experiment Station, 1927-1942, 1928-1942, and Fisheries Research and Development Agency, 1964), depth and deposits (Fisheries Experiment Station, 1937, and Fisheries Research and Development Agency, 1964).

RESULTS

(1) WATER COLOR DISTRIBUTIONS

The horizontal distributions of average water color in the seas around Korea show two patterns as shown in Fig. 2; the one is the East Sea and the South Sea, the other is the Yellow Sea.

The average water colors of the East Sea and the South Sea are 3.7 in Forel scales; and show 4.7 at 2 miles from seashore, 3.8 at 25 miles, 3.4 at 50 miles, on an average.

The relation between the water color and the distance from the seashore in the East Sea and the South Sea is as follows;

$$C_E = 5\ e^{-k\sqrt{x}} \qquad \cdots\cdots\cdots\cdots(1\text{-}1)$$

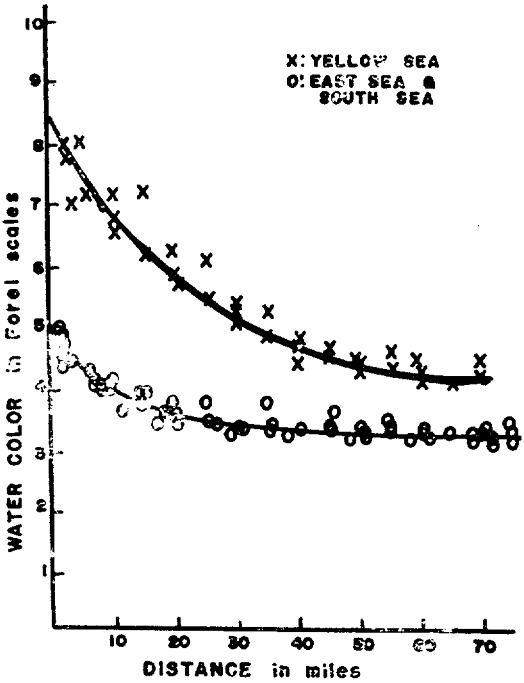


Fig. 2. The horizontal distributions of average water color.

$$k = 0.056\ \text{mile}^{-\frac{1}{2}}$$

where C_E is the water color in Forel scales (1 to 11) in the East Sea and the Southh Sea, x is the distance from seashore in miles. And the maximum values of water color show in May, minimum in August, on an average, but monthly variations are not clear at shore stations within observational error.

In the Yellow Sea, it is 5.6 in Forel scales and maximum value shows in February, minimum in September, on an average. The relation between the water color and the distance from the seashore in the Yellow Sea is given by

$$C_Y = 8.5\, e^{-k\sqrt{x}} \quad \cdots\cdots\cdots\cdots (1\text{-}2)$$

$$k = 0.086\ \text{mile}^{-\frac{1}{2}}$$

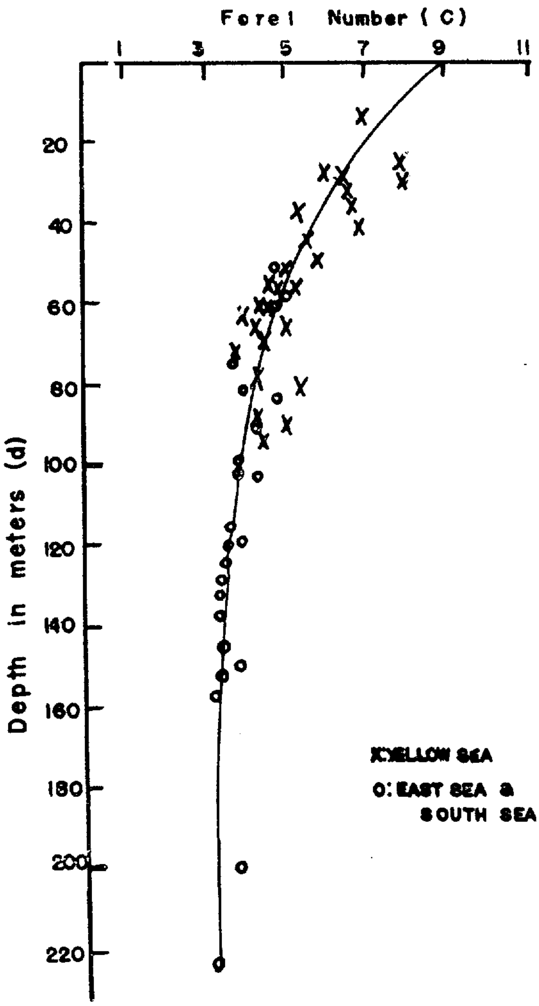
The water color distributions by depth, as shown in Fig. 3, are 6.8 in Forel scales at 30 m depth, 5.2 at 60 m, 3.1 at 120 m, on averages. And so the formula is given by

$$C = 9\, e^{-kd} \quad \cdots\cdots\cdots\cdots\cdots (1\text{-}3)$$

$$k = 0.009\ \text{m}^{-1}$$

in the seas around Korea. In this formula, d is depth in meters.

Fig. 3. Average water color distributions by depth in the seas around Korea.

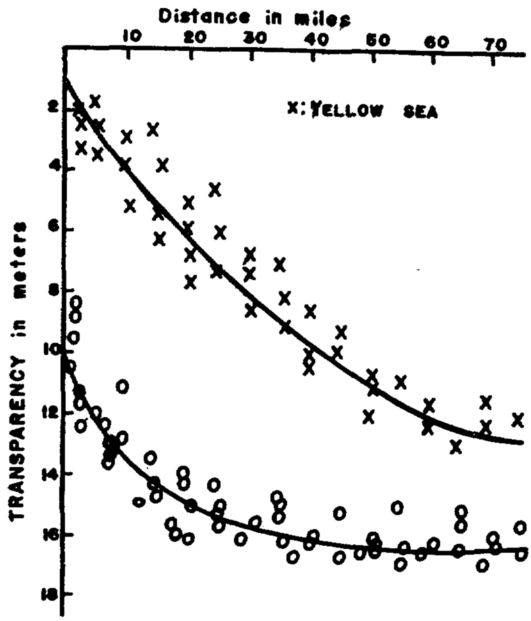


(2) TRANSPARENCY DISTRIBUTIONS

The horizontal distributions of average tranparsency in the seas around Korea show two patterns as shown in Fig. 4, similar to water color. The average transparencies of the East Sea and the South Sea are 15 m, and show 11 m at 2 miles from seashore, 15 m at 25 miles, 16 m at 50 miles, on averages, and the transparency T_E is given by

$$T_E = k_1\sqrt{x} + k_2 \qquad \cdots\cdots\cdots\cdots(2\text{-}1)$$

Fig. 4. The horizontal distributions of average transparency.



where $k_1 = 0.9$ m $\text{mile}^{-1/2}$

$k_2 = 10$ m

The Yellow Sea is different from the East Sea and the South Sea: the farther it is from sea shore, the transparency is the deeper almost linearly in this sea, and average transparency shows 7 m.

$$T_Y = k_1\sqrt{x} + k_2 \cdots\cdots(2\text{-}2)$$

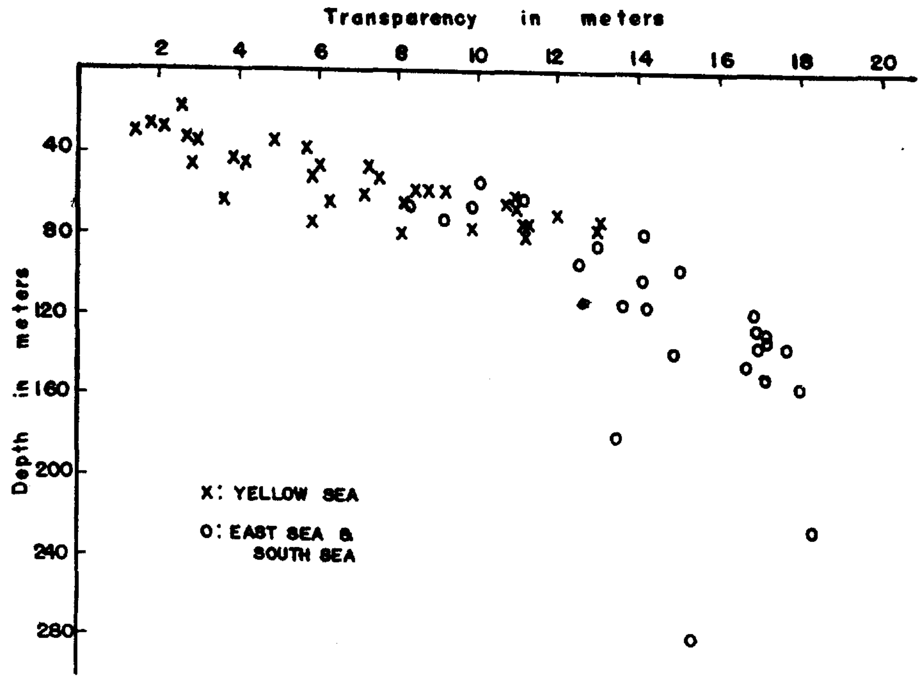
where $k_1 = 1.2$ m $\text{mile}^{-1/2}$

$k_2 = 1$ m

The lowest transparencies show in May in the East Sea and the South Sea, but the deepest transparencies show in September in both of them, on averages.

The transparency caused by depth is shown in Fig. 5. It is in direct proportion to depth roughly within continental shelf around Korea, but it is independent of depth in the deep sea and almost constant.

Fig. 5. Average transparency distributions by depth in the seas around Korea.



(3) THE RELATIONSHIP BETWEEN THE WATER COLOR AND THE TRANSPARENCY

When the water color shows the maximum value, the transparency shows the minimum. The water color shows 8.5 in Forel scales when the transparency shows 1 m, 6.6 at 5 m, 4.9 at 10 m, and 3.6 at 15 m: and the relationship between the water color and the transparency in the seas around Korea is given by following,

$$C=9e^{-\kappa T} \qquad \cdots\cdots\cdots\cdots\cdots\cdots(3\text{-}1)$$

$$k=0.0625\,m^{-1}$$

where C is the water color in Forel scales, T is the transparency in meters. The water color is an exponential function of transparency as shown in Fig. 6.

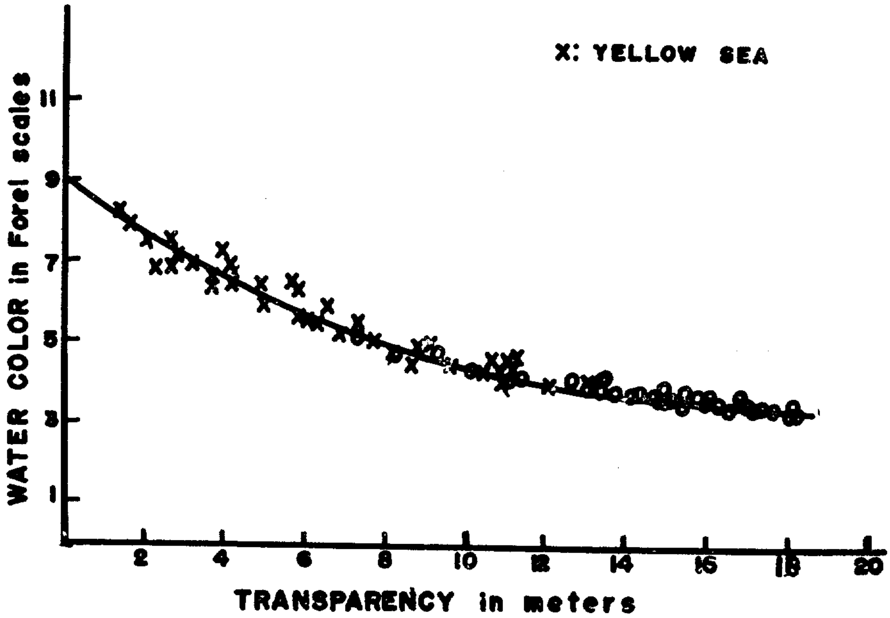


Fig. 6. The relationship between the water color and the transparency in the seas around Korea.

DISCUSSION

The water color in Forel scale decreases with the distance from the seashore and depth; the transparency increases with the distance and depth. They are caused by suspended particles, especially suspended clay. Suspended clay is the major factor in the change in color and transparency, particularly in the Yellow Sea.

In the Yellow Sea, deposits are mud, sand, and pebbles, depth is within 100 m, high tide about 8 m, strong circulation, and most of the rivers in Korea run into this sea. So these contribute very much to suspended clay. Daily deposit at Taeya-Do is an average of 0.28 g/cm^2(Kurasige, 1943).

In the East Sea and the South Sea, deposits are sand, shells, pebbles, mud and rocks. The daily deposit at Dadaepo, Pusan, is only 10% that of Taeya-Do in the Yellow Sea (Kurasige, 1943). In the South Sea, the depth is within 200 m and high tide averages 3 m. In the East Sea, depth is 1700 m on an average and the highest tide is only 0.5 m.

The constants k_2, formula (2-1) and formula (2-2), agree with Kurasige's observations of daily deposits. According to these formulas the transparencies along the East Coast line and the South Coast line are 10 m, and 1 m along the West Coast line in Korea.

The formula (3-1) which shows water color —transparency relation is induced from the empirical formulas, horizontal distributions of the water color, and horizontal distributions of the transparency.

Table 3. Comparative table among the water color values of formula (3-1), (3-2), (3-3) and observed values in Forel scales according to transparencies.

Water Color \ Transparency	0m	1m	5m	10m	15m
Observed Value	—	8.5	6.6	4.9	3.6
$C=9\ e^{-0.0625T}$	9.0	8.5	6.6	4.8	3.5
$C_Y=8.5\ e^{-0.086\left(\frac{T_Y-1}{1.2}\right)}$	9.0	8.5	6.5	4.6	3.2
$C_E=5\ e^{-0.056\left(\frac{T_E-10}{0.9}\right)}$	9.2	8.7	6.8	5.0	3.6

From formula (2-1)

$$\sqrt{x}=\frac{T_E-10}{0.9}$$

therefore formula (1-1) becomes following:

$$C_E=5\,e^{-0.056\left(\frac{T_E-10}{0.9}\right)} \quad \cdots\cdots(3\text{-}2)$$

From formula (2-2)

$$\sqrt{x}=\frac{T_Y-1}{1.2}$$

therefore fomula (1-2) is given by

$$C_Y=8.5\,e^{-0.086\left(\frac{T_Y-1}{1.2}\right)} \quad \cdots\cdots(3\text{-}3)$$

The empirical formula (3-1) and the calculated formula (3-2), (3-3) have coincident values among them within the limits of error,as shown in Table 3.

The horizontal distributions of average water color and the transparency in the seas around Korea show two patterns as shown in Fig. 2 and Fig. 3: the one is the East Sea and the South Sea, the other is the Yellow Sea. In the Yellow Sea, the water is color light green, 5.6 in Forel scales and the transparency is 7 m on an average. In the East Sea and the South Sea, they are bluish green, 3.7 in Forel scales, and transparencies are 15 m on averages.

In September, the transparency shows the maximum value and the water color shows the minimum. And the water color shows an exponential function of transparency with amplitude 9, formula (3-1).

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