Proposal of the environmental quality index in Northeast Asia ports

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Abstract:
The environmental guideline of the harbor management was suggested and assigned as the joint research subject in the 18th Northeast Asia Port Director-General Meeting held by China, Japan, and Korea. The purpose of this research is to present and evaluate the harbor environmental standards, which are evaluated and managed at different standards, methods, and grades, by one common standard agreed by the three countries. As a result, a common index, which is expressing overall environmental conditions in harbor area, was introduced. This is the first step aiming to the common understanding and united management of the Northeast Asian harbor environment.

Keywords: air quality, water quality, sediment quality, integrated quality index

1. Introduction

As the growing of globalization, vessel traffic across borders has been intensively activated. This tendency is expected to become more increased in near future. Under such conditions, environmental connection across the countries will also become tighter and we need to share the common view concerning harbor environmental management.
In the case of using their own national standards, it was impossible to compare harbor environment management with neighbouring countries. Therefore, the scope of management was limited to its own harbor environmental grade evaluation and it was difficult to follow international (or same) environmental management level. However, if one agreed to use a common standard to assess a country's harbor, it is possible to compare harbor environmental management grades with neighbouring countries on an equivalent level.
In this context, the environmental guideline of the harbor management was suggested and assigned as the joint research subject in the 18th Northeast Asia Port Director-General Meeting held by the Transport and Logistics Ministers of China, Japan, and Korea. The purpose of this research is to present the harbor environmental standards, which have been evaluated and managed at different standards, methods, and grades, as one common standard agreed by the three countries.
In order to apply the common standard, there is a limitation that the monitoring data on the same environmental parameters must be used to apply the standard. Therefore, the application of this joint common standard is not a strong recommendation on a strict scientific knowledge, but a basic criterion for recommendation and suggestion as a guideline, and is appropriate as a reference for comparison with neighbouring countries. In addition, if the common monitoring data is extended and shared for more environmental and ecological parameters, the joint criteria may add ecological harbor management factors to reflect the data availability.
The environmental guidelines proposed in this research work include the basic concepts and detailed computational methods that can be checked and applied by China, Japan, and Korea. In general, even though the harbor environmental standard has a process for evaluating each factor, a grade is presented as many as the number of environmental parameters to be applied, which may cause a very complicated situation because of too much information. In order to avoid this problem, an integration method of the diverse grade levels as one factor (index) is introduced, which have been introduced lately and used internationally.
In this paper, transitions of environmental administration in harbor area in the three countries were briefly summarized in each section. After that, monitoring items by the three countries were reviewed, and an overall index for air, water, and sediment quality employing common monitoring items was introduced.

2. Computation methods for environmental indices

First, a survey was conducted on environmental measurement items, environmental reference values, and environmental assessment indicators in the three countries. Based on them, the following indicators were proposed for air quality, water quality, and sediment quality.

2.1. Air quality index

Purpose of air quality assessment

The air quality index (AQI) is an index for reporting daily air quality. It tells the public how clean or polluted the air is, and what associated health effects might be a concern for the public. The AQI focuses on health effects people may experience within a few hours or days after breathing polluted air. The United States Environmental Protection

Agency first developed AQI and some other countries used the similar index system to develop their own AQIs, including China and Korea. In common, the AQI is usually calculated for several major air pollutants regulated by its developer, such as the Clean Air Act regulates the ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulphur dioxide, and nitrogen dioxide as the five major air pollutants in the U.S. For each of these pollutants, the developer establishes its national air quality standards to protect public health.

The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, in the U.S. an AQI value of 50 represents good air quality with little or no potential to affect public health, while an AQI value over 300 represents air quality so hazardous that everyone may experience serious effects.

An AQI value of 100 generally corresponds to the national air quality standard for the pollutant, which is the level the developers have set to protect the public health. AQI values at or below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered unhealthy—at first for certain sensitive groups of people, then for everyone as AQI values increase.

The purpose of the AQI is to help people understand what local air quality means to the public health. To make it easier to understand, the AQI is divided into several levels of health concern, according to which different groups of people could protect their health with relative measures.

The AQI is usually a national index, so the values used to show local air quality and the levels of health concern are the same everywhere in the same developer [1,2,3].

Indices

The air quality standards of China, Japan, and Korea were compared to seek the comparable main pollutants for the uniformed AQI [4,5,6]. It was found that the six main pollutants adopted by China and Korea are same. However, among these six pollutants, five of them are daily monitored but the photochemical oxidants are monitored instead of ozone for the purpose of air quality assessment in Japan. The five main pollutants are daily monitored in all three countries are NOx, SOx, PM10, PM2.5, and CO with their concentration limits and measuring methods in three countries, respectively. Therefore, these five substances could be the main pollutants of the uniformed AQI.

Proposal for the uniformed AQI

China and Korea have developed their own AQI systems following the U.S. while Japan does not conduct such initiative. The calculating equations of the air quality index for each target pollutant are same for China and Korea, however the calculating variables and the equations for calculating the comprehensive AQI are different. The AQI-C_P (C_P: the rounded concentration of each target pollutant) curves for Korean standard change more gently than Chinese ones so that when ordinary Cps of the air pollutants are relatively low in Korea, the AQI for each main pollutant with larger variance is able to markedly reflect the change trend of the air qualities. Finally, we recommended the AQI calculating method used by Chinese government for the ports in China, Japan, and Korea. Thus, this AQI is able to reflect the overall perspective of the air quality of the ports in the North-East Asia. The slight adjustments to this method are:

(a) only 24-hour Cps are used for the calculation;

(b) ozone is ignored during the calculation since it is not separately monitored by Japan;

and (c) the comprehensive AQI equals to the average of all the indices instead of the maximum value among them, as all the target pollutants are equally weighed for the air quality assessment.

The proposed calculating equation is listed below.

$$IAQIp = (IAQI_{HI} - IAQI_{LO})/(BP_{HI} - BP_{LO}) \times (Cp - BP_{LO}) + IAQI_{LO} \quad (1)$$

where, $IAQIp$ = the air quality index for each target pollutant; Cp = the rounded concentration of each target pollutant; BP_{HI} = the breakpoint that is greater than or equal to Cp ; BP_{LO} = the breakpoint that is less than or equal to Cp ; $IAQI_{HI}$ = the index value corresponding to BP_{HI}; and $IAQI_{LO}$ = the index value corresponding to BP_{LO}.

$$AQI = (IAQI_1 + IAQI_2 + IAQI_3 + IAQI_4 + IAQI_5)/5 \quad (2)$$

The variables required in calculating AQI are listed in Table 1. For instance, observed SO_2 concentration is 0.01 ppm, BP_{HI} =0.019 ppm, BP_{LO}=0.0 ppm, $IAQI_{HI}$ =50, $IAQI_{LO}$ =0, respectively. Grade evaluations based on the calculated AQI are listed in Table 2.

2.2. Water quality index

Purpose of water quality assessment

Marine ecosystems are complex and delicate. Water quality standards help protect these ecosystems by ensuring that key parameters such as nutrient levels, oxygen content, and pollutant concentrations remain within acceptable limits. Likewise, many marine species are highly sensitive to changes in water quality. Setting standards helps preserve biodiversity by maintaining suitable conditions for various organisms, from microorganisms to larger marine life. In recent years, the value of ports as places for recreation is increasing. Clean and healthy marine environments are attractive to tourists and many people engage in recreational activities in marine environments. In these points of view, water quality is one of the most important aspects of a port's landscape.

Healthy marine environments are essential for fisheries and aquaculture. Water quality standards contribute to sustainable fishing practices and support the growth of aquaculture industries by

Table 1 The variables required in calculating AQI

Same Substance	Period	IAQI	0	50	100	150
SO_2	Daily average	Break point (BP) of pollutant concentration	0	0.019 ppm	0.057 ppm	0.181 ppm
NO_2	Daily average		0	0.021 ppm	0.043 ppm	0.096 ppm
CO	Daily average		0	1.75 ppm	3.492 ppm	12.221 ppm
PM_{10}	Daily average		0	50 µg/m³	150 µg/m³	250 µg/m³
$PM_{2.5}$	Daily average		0	35 µg/m³	75 µg/m³	115 µg/m³
Same Substance	Period	IAQI	200	300	400	500
SO_2	Daily average	Break point (BP) of pollutant concentration	0.305 ppm	0.611 ppm	0.802 ppm	1.000 ppm
NO_2	Daily average		0.149 ppm	0.300 ppm	0.399 ppm	0.500 ppm
CO	Daily average		20.950 ppm	31.425 ppm	41.900 ppm	52.374 ppm
PM_{10}	Daily average		350 µg/m³	420 µg/m³	500 µg/m³	600 µg/m³
$PM_{2.5}$	Daily average		150 µg/m³	250 µg/m³	350 µg/m³	500 µg/m³

Table 2 The grade evaluations based on the calculated AQI

AQI Value	Actions to Protect Public Health From the Main Pollutants			
	SO_2	NO_2	CO	PM_{10} / $PM_{2.5}$
Good(0–50)	None	None	None	None
Moderate (51–100)	None	None	None	Unusually sensitive people should consider reducing prolonged or heavy exertion.
Unhealthy for Sensitive Groups (101–150)	People with asthma should consider reducing exertion outdoors.	People with asthma should consider reducing exertion outdoors.	People with heart disease, such as angina, should reduce heavy exertion and avoid sources of carbon monoxide, such as heavy traffic.	The following groups should reduce prolonged or heavy exertion: • People with heart or lung disease • Children and older adults
Unhealthy (151–200)	Children, asthmatics, and people with heart or lung disease should reduce exertion outdoors.	Children, asthmatics, and people with heart or lung disease should reduce exertion outdoors.	People with heart disease, such as angina, should reduce moderate exertion and avoid sources of carbon monoxide, such as heavy traffic.	The following groups should avoid prolonged or heavy exertion: • People with heart or lung disease • Children and older adults Everyone else should reduce prolonged or heavy exertion.
Very Unhealthy (201–300)	Children, asthmatics, and people with heart or lung disease should avoid outdoor exertion. Everyone else should reduce exertion outdoors.	Children, asthmatics, and people with heart or lung disease should avoid outdoor exertion. Everyone else should reduce exertion outdoors.	People with heart disease, such as angina, should avoid exertion and sources of carbon monoxide, such as heavy traffic.	The following groups should avoid all physical activity outdoors: • People with heart or lung disease • Children and older adults Everyone else should avoid prolonged or heavy exertion.

ensuring that aquatic organisms are raised in optimal conditions. Overall, WQI help protect marine ecosystems from pollution and degradation. This index should be established to show the acceptable levels of various items to maintain a healthy and balanced port environment. This is essential for the preservation of biodiversity and the health of aquatic ecosystems, resulting an ideal port's landscape, fisheries, and aquaculture.

Indices

The water quality standards of China, Japan and Korea were compared to seek the comparable items for the uniformed WQI. In these three countries, water quality is generally monitored monthly to seasonally. The common water quality parameters agreed by three countries are dissolved oxygen (DO), chemical oxygen demand (COD),

Table 3 Reference values of the water quality parameters for common WQI computation

	Bottom DO saturation ratio (%)	Surface DIN (μg/L)	Surface DIP(μg/L)	COD (mg/L)
R_v (Ref. value)	90	230	25	2.0

Table 4 Scores of the WQ parameters based on the reference concentrations

Scores	WQ parameters	
	DIN(μg/L), DIP(μg/L), COD(mg/L)	DO (saturation ratio)
1	Below reference value (R_v)	Above reference value (R_v)
2	$< R_v + 0.10R_v$	$>$ Rv – $0.10R_v$
3	$< R_v + 0.25R_v$	$>$ Rv – $0.25R_v$
4	$< R_v + 0.50R_v$	$>$ Rv – $0.50R_v$
5	$>= R_v + 0.50R_v$	$<=$ Rv – $0.50R_v$

nitrogen, and phosphorus concentration. For COD, nitrogen, and phosphorus, the values measured in the surface layer should be used to express the concern due to eutrophication, which is still serious problem in port area. On the other hand, DO in the bottom layer should be employed to evaluate the development of hypoxia or anoxia triggered by a density stratification.

In this study, Korean WQI was recommended to be employed. In order to use the Korean WQI, the transparency and chlorophyll-a concentration is used. However, the common water quality parameters do not include above two parameters. Therefore, the WQI computation method should be changed to new one as the function of the four parameters listed above.

Proposal for the uniformed WQI

The finally proposed calculating equation was formulated as below:

$$WQI = 10DO_{score} + 6COD_{score} + 2(DIN_{score} + DIP_{score}) \quad (3)$$

where, each score (DO_{score}, COD_{score}, DIN_{score}, DIP_{score}) is estimated from R_v (reference value) (Table 3) and method (Table 4). For example, observed DIN is less than R_v (=230μg/L), the DIN_{score} become 1. When observed DIN is ranged from R_v to 1.1R_v, the DIN_{score} become 2. Other scores are estimated in the same manner above. Finally, substituting the estimated scores to equation (3) and then estimating WQI from Table 5

Table 5 Evaluation of WQI and SQI

Grade	WQI	SQI
very good	Below 23	0~10
good	24~33	10~30
normal	34~46	30~50
poor	47~59	50~70
very poor	Above 60	70-100

2.3. Sediment quality index

Purpose of sediment quality assessment

As chemicals or substances are released into the environment through natural processes or human activities, they may enter aquatic ecosystems and partition into the particulate phase. These particles may be deposited to the sea floor where the contaminants may accumulate over time. The primary source of contaminants in sediments is toxic chemicals from industrial and municipal discharges of water. The runoff from cities, towns, and agricultural areas may also contribute to the problem [7].

Sediments may therefore act as long-term reservoirs of chemicals to the aquatic environment and organisms living in or having direct or indirect contact with sediments. Because sediments comprise an important component of aquatic ecosystems, providing habitat for wide range of benthic and epibenthic organisms, exposure to certain substances in sediments represents a potentially significant hazard to the health of the organisms [8].

Sediment quality guidelines (SQGs) are potential tools that synthesize information regarding the relationships between the sediment concentrations of chemicals and any adverse biological effects resulting from exposure to these chemicals [8]. And they provide scientific benchmarks, or reference points, for evaluating the potential for observing adverse biological effects in aquatic systems. However, the most of SQGs, which developed during the past 20 years to assist regulators in dealing with contaminated sediments, have been developed in North America. Those proposed in Asian region have hardly seen so far from the authors' knowledge.

In that context, a common procedure is required to develop informal guidelines or recommendations to evaluate sediment quality collected in North-East Asian countries. In this section, therefore, the procedure basically following the CCME, but with North-East Asian countries' sediment standard thresholds, is introduced.

Indices

The sediment quality index (SQI) should be a quantitative tool to assess and rate contaminated site. The index can also be used to compare the sites before and after remediation and to see if the jurisdictional requirements have been met for a particular site.

In this study, the authors' aims for establish the simple and workable index to evaluate the environmental condition in a port region. The index should be; 1) calculated using existing observed items among the three countries; 2) calculated with simple and clear procedure; 3) consistent with traditional evaluation in each country.

Based on the on-going monitoring in three countries, total sulfide (TS), arsenic (As), cadmium (Cd), chrome (Cr), and zinc (Zn) are employed as parameters in the calculation of SQI. In this paper, TS threshold was set to be the same value as the Japanese quality standards for fishery water, that is, 0.2 mg g-dry-sed^{-1}. On the other hand, Long et al. (1995) [9] introduced the effects range-low (ERL) values, which is the lower 10th percentile of the biological effects data, as a standard for biological impact assessment. Naito et al. (2008) [10] summarized that those values can be a standard benchmark also in Japan. Therefore, in this study, we employed the ERL values as the threshold for heavy metals, that is, 8.2 mg kg-dry-sed^{-1} for As, 1.2 mg kg-dry-sed^{-1} for Cd, 81 mg kg-dry-sed^{-1} for Cr, and 150 mg kg-dry-sed^{-1} for Zn, respectively.

Proposal for the uniformed SQI

In the CCME procedure, three factors are defined to calculate the SQI, namely: 1) scope ($F1$, % of the number of items that do not meet their respective guidelines), 2) frequency ($F2$, % of individual tests of items that do not meet their respective guideline), 3) amplitude ($F3$, the amount of deviation from their respective guideline). A brief description of these factors and formulae for calculating the index are as follows:

The factor $F1$ (Scope) represents the percentage of contaminants that do not meet their respective guidelines (failed contaminants) relative to the total number of contaminants that were measures (and selected for inclusion in SQI calculation) at the site.

$$F1 = \frac{Number\ of\ failed\ contaminants}{Total\ number\ of\ contaminants} * 100 \quad (4)$$

The factor F2 (Frequency) represents the percentage of individual tests that do not meet their respective guidelines (failed tests):

$$F2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} * 100 \quad (5)$$

The factor F3 (Amplitude) represents the amount by which failed test values do not meet their respective guidelines (excursion from the guideline value). F3 is calculated in the following three steps.

Step 1: Calculate the excursion of all tests in the dataset:

When the concentration of a contaminant is greater than (or less than, when the guideline is a minimum) the soil quality guideline, it is called an excursion. The magnitude of excursion of each test is calculated as follows:

When the test value must not exceed the guideline:

$$Excursion_i = \frac{Failed\ Test\ Value_i}{Guideline_i} - 1 \quad (6a)$$

For the cases in which the test value must not fall below the guideline:

$$Excursion_i = \frac{Guideline_i}{Failed\ Test\ Value_i} - 1 \quad (6b)$$

Step 2: Calculate the average sum of excursions or 'ase'

They refers to the average amount by which individual tests are out of compliance and is calculated by summing the excursion of all individual tests from their guidelines and dividing by the total number of tests that do not meet their guidelines as follows:

$$ase = \frac{\sum_{i=1}^{n} excursion_i}{number\ of\ failed\ tests} \quad (7)$$

Step 3: F3 is then calculated by an asymptotic function that scales the average sum of excursions (ASE) to yield a range between 0 and 100 as follows:

$$F3 = \frac{ase}{(0.01ase + 0.01)} \quad (8)$$

Once the factors have been quantified, the SQI can be calculated by summing all the factors as if they were vectors as shown below in eq. (9). This approach treats the index as a three dimensional space defined by each factor along one axis. With this model, the index changes in direct proportion to change s in all three factors.

$$SQI = \frac{\sqrt{F1^2+F^2+F^3}}{1.732} \quad (9)$$

The divisor (1.732) normalizes the resultant values to a range between zero and one hundred, where zero represents a very high level of contamination or public concern and one hundred represents negligible amount of contamination or public concern. The value of the divisor is calculated as follows:

$$\frac{\sqrt{100^2+100^2+100^3}}{100} = 1.732 \quad (10)$$

SQI is classified into five grades (Table 5). A low SQI score indicates high quality and have a very low contaminant level. Therefore, these would be low priorities for remediation. On the other hands, a large SQI score would indicate a very high level of contaminant, and therefore being highly required for remediation.

3. Discussion

Difference between Korean WQI and present WQI

In this study, the present WQI is based on Korean WQI. In Korea, water quality is evaluating for Korean WQI [11, 12]. Therefore, we think both of the methods should show the similar results. However, these results weren't similar (Figure 1). This is because the R_v is fixed in the present WQI. R_v must be vary depending on the place [13]. In future study, we will study how to determine the R_v in the arbitrary location.

Integration diagram: AQI, WQI, and SQI visualization

In order to integrate, the modified ternary diagram is suggested for AQI, WQI and SQI (Figure 2). To draw the ternary diagram, the three lines should be defined unlikely a typical pattern. Tri-angle center is the origin (or starting point, the biggest score of the three indices), and three lines is formed from the origin to the three vertices. These three lines are used to show each index scores. In order to draw the diagrams, every index scores should be adjusted from 0 to 100.

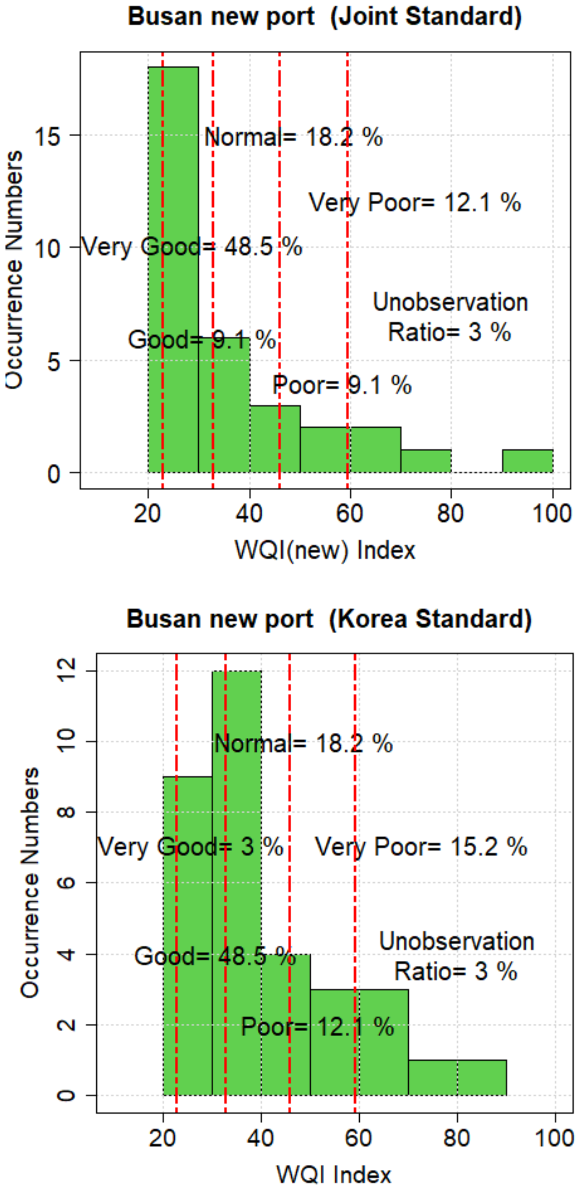

Figure 1 Comparison between present WQI and Korean WQI. Upper figure showed the result from present WQI. Below figure showed the one from Korean WQI. The left region from the first left dashed line is very good water quality. Good water quality region is between first and second from the left dashed line. Normal water quality region is between second and third, Poor water quality is between third and fourth, and very poor water quality is right region from the right dashed line.

4. Conclusions

In this paper, a common index, which is expressing overall environmental conditions in harbor area in China, Korea, and Japan, was introduced. This result was obtained from the joint research project of the Northeast Asia Port Director-General Meeting. This is the first step aiming to the common understanding and united management of the Northeast Asian harbor environment and some progresses will be required. For example, employed monitoring items are not enough and more items are expected to be monitored in the same manner (frequency, analytical method, etc.) among the countries.

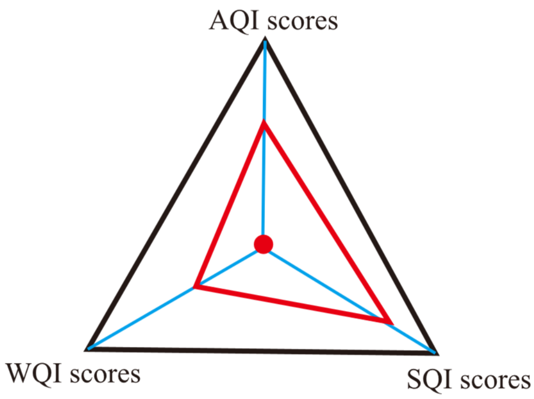

Figure 2 Ternary diagram for evaluating the environment

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