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Corrosivity of Atmospheres in the Korean Peninsula

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The Korean Peninsula is located in the middle latitude of the northern hemisphere and has a clear 4-seasons and shows the typical temperate climate. Because of seasonal winds, it is cold and dry by a northwestern wind in the winter and it is hot and humid by a southeast wind in the summer. Also, temperature difference between the winter and the summer is large and it shows a rainy season from June to July but recently this regular trend may be greatly changed by an unusual weather phenomena. Since the Peninsula is east high west low type, the climate is complicated too. Because these geographical and climate characteristics can affect the properties of corrosion of metals and alloys, a systematic research on atmospheric corrosion in the Peninsula is required to understand and control the corrosion behavior of the industrial facilities. This paper analyzed the atmospheric corrosion factors for several environments in the Korean Peninsula and categorized the corrosivity of atmospheric corrosion of metals and alloys on the base of the related ISO standards. Annual pH values of rain showed the range of 4.5~5.5 in Korean Peninsula from 1999 to 2009 and coastal area showed relatively the low pH's rain. Annual SO_2 concentrations is reduced with time and its concentrations of every major cities were below the air quality standard, but NO_2 concentration revealed a steady state and its concentration of Seoul has been over air quality standard. In 2007, SO_2 classes of each sites were in P_0~P_1, and chloride classes were in S_0~S_1, and TOW classes were in τ_3~τ_4. That is, SO_2 and chloride classes were low but TOW class was high in Korean Peninsula. On the base of these environmental classes, corrosivity of carbon steel, zinc, copper, aluminium can be calculated that carbon steel was in C2-C3 classes and it was classified as low-medium, and zinc, copper, and aluminium showed C3 class and it was classified as medium.

Keywords *: corrosivity, metals and alloys, korean peninsula, atmospheric environment factor*

1. Introduction

Metals and alloys corrode in natural atmospheric environments with various humidities. Water in the atmosphere can adsorb or condensate on the surface and then forms thin film (~200 um). Some polluted species like oxygen dissolve into water film and form the electrolytes resulting in atmospheric corrosion.[1)-2)] The corrosive environment includes the water film on the metal surface, oxygen in the air, dissolved polluted species from the air to water, and adsorption of some particles etc. Factors affecting atmospheric corrosion are chemical parameters such as the amount of dissolved oxygen, ozone, moisture, sulfur dioxide, salt, acid rain deposited on the metal surface and physical parameters like temperature, the strength of wind and sunlight. These factors vary with natural environment and in seasons. The environmental factors and atmospheric corrosion environment have been reported to influence the corrosion properties of metals and alloys.[3)-7)]

The atmospheric corrosion have been reported in various environments in many countries for several decades. The works on atmospheric corrosion include ISO CORRAG Collaborative Exposure Program,[8)-10)] MICAT (Iberoamerican Atmospheric Corrosion Map Project),[10)-14)] ICP/UNECE Program,[15)-17)] North-East Asia Program.[18)] In recent years, many researches on atmospheric corrosion have been in progress in collaboration with ISO CORRAG Program.[19),20)] In Korea, atmospheric corrosion was reported only in Jeju

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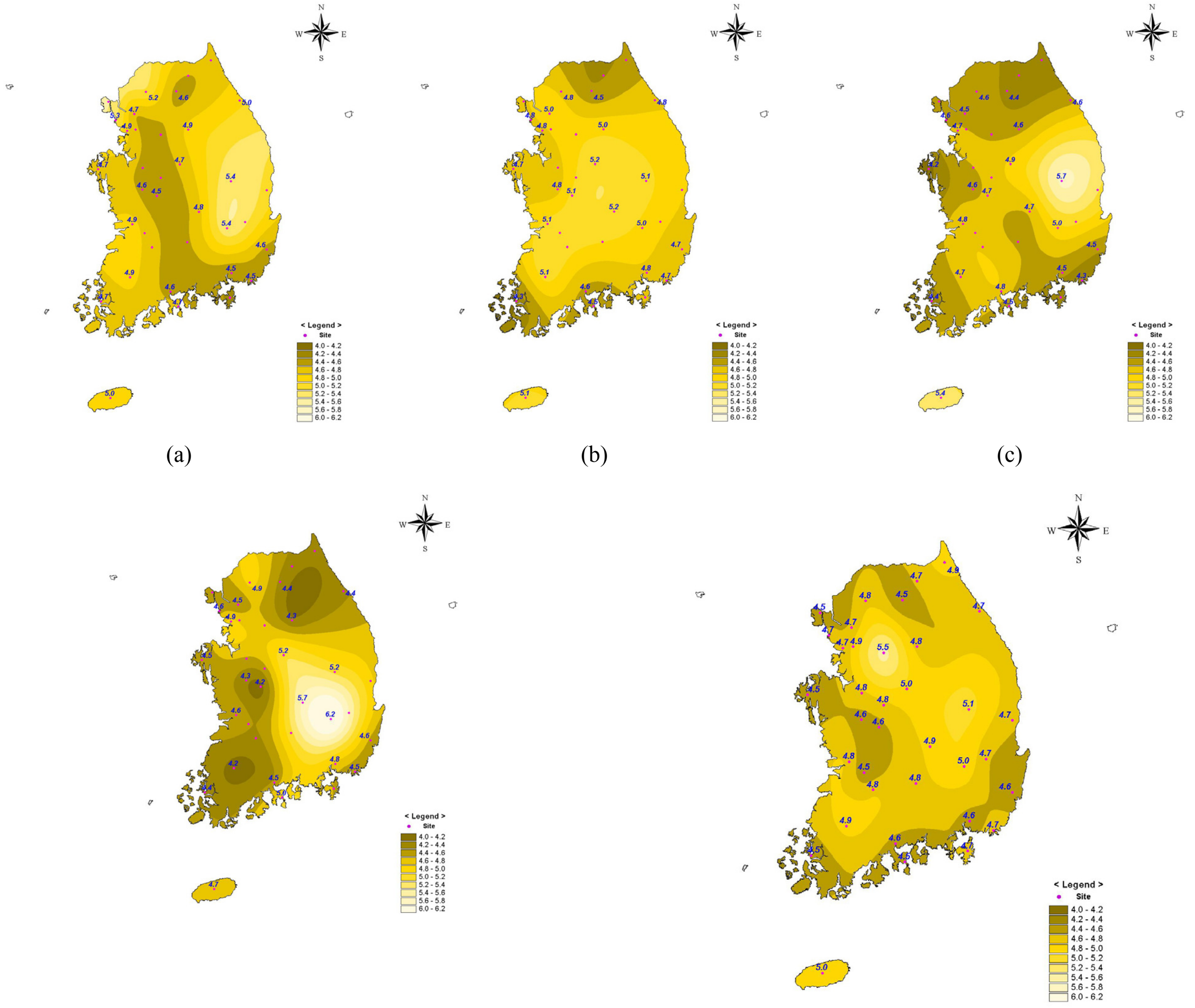
island on the basis of environmental index in 2004,[21] and the Corrosion Science Society of Korea has been performing the work on the determination of corrosion rate of various metals and alloys since 2006.[22],[23]

Corrosivity of atmospheres can be determined by outdoor exposure test on the basis of the environmental factors such as the time of wetness, concentrations of SO_2 and chloride deposition.[24] The corrosivity is usually determined in marine, industrial, urban, and rural regions and the durability of metallic materials depends upon the environments in which the materials are used, and the detail understanding is needed about the service environments.

The Korean Peninsula is located in the middle latitude of the north hemisphere with four distinct seasons and typical temperate climate. Because of seasonal winds, it is cold and dry by the northwestern wind in the winter and hot and humid by the southeast wind in summer. Also, temperature difference between winter and summer is large with a rainy season from June to July, but recently this typical trend has greatly been changed by the unusual weather phenomena. Since the Peninsula is east high west low, the climate is complicated. Because these geographical and climate characteristics can affect the properties of corrosion of metals and alloys, a systematic research on atmospheric corrosion in the Peninsula is needed to understand and control the corrosion of the industrial facilities.



(a) (b) (c)

(d) (e)

Fig. 1. pH map of rain; (a) spring, (b) summer, (c) autumn, (d) winter, and (e) annual average of the Korean Peninsula at 2009.

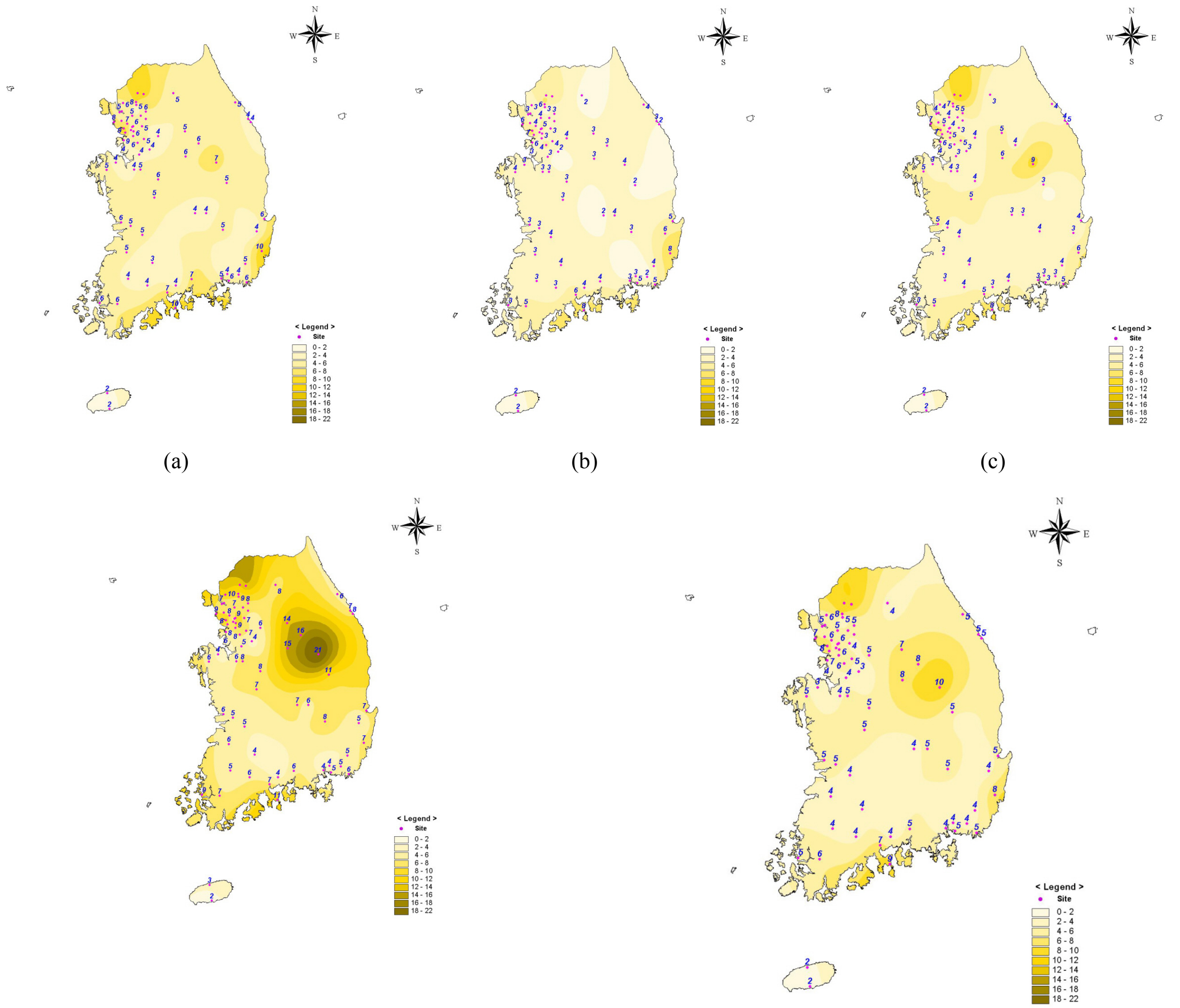


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Fig. 2. SO_2 concentration map; (a) spring, (b) summer, (c) autumn, (d) winter, and (e) annual average of the Korean Peninsula at 2009. (unit: ppb)

This paper presents the results of atmospheric corrosion tests in terms of the corrosivity of atmospheres in various test sites in marine, industrial, urban, and rural regions in the Korean Peninsula which are analyzed on the basis of the related ISO standards.

2. Experiments

The pH of rain was measured using a glass electrode method, the concentration of SO_2 was determined by pulse U.V. florescence method and the concentration of NO_2 was analyzed by chemi-luminescent method in Andong, Jochiwon, Asan, Seosan, Dangjin, Seoul Shinchon and Anam, Gwangju, Goyang, Suwon, Ansan, Busan, Incheon, Ulsan, Pohang, Gangneung, Chuncheon, Mokpo, Gunsan, and Gwangyang regions, except in 2009 in which the data were collected from the Meteorological Administration of Korea.

Atmospheric corrosivity was evaluated according to ISO 9223 and ISO 9225 based on the environmental factors and corrosion rate of the standard metallic materials.[24),25)] Time of wetness and concentrations of SO_2 and chloride were used to evaluate the atmospheric corrosivity which were collected from the environmental measuring devices at each sites. Time of wetness was determined by the length of time when the relative humidity is greater than 80% at the temperature above 0 ℃.

3. Results and discussion

3.1 Atmospheric environment of the Korean Peninsula

Fig. 1 shows the pH map of rain in 2009 for spring (a), summer (b), autumn (c) and winter (d) and annual average (e). The pH in summer was higher than others but with some regional variations. According to the data of the Ministry of Environment of Korea,[26)] mean annual rainfalls were 1100~1400 mm for central region, 1000~1800 mm for southland, 1000~1200 mm for Gyeongbuk area, 1800 mm for Gyeongnam coastal area, 1450~1850 mm for Jeju island, and 50~60% of annual rainfall was precipitated in summer. Higher pH in summer was due to the large amount of rainfall in the rainy season from June to July. As in Fig. 1(c) and (d), pH of the eastern coast was higher than the west coast. This is also due to the amount of rainfall which is larger in east coast than west coast in autumn and winter. The pH of rain in the Korean Peninsula varies with season, and mean annual pH values of rain are in the range of 4.5~5.5; the pH of rain in the Ganghwa, Chuncheon, Taean, Jeonju are close to the mean, 4.5 and the highest, 5.5 in Icheon area. In addition, the pH of rain in coastal areas are low.

Fig. 2 shows SO_2 concentration map; for spring (a), summer (b), autumn (c), winter (d) and annual average (e) in the Korean Peninsula in 2009. The concentrations of SO_2 in spring and winter were higher than others. Expecially, SO_2 concentration in winter was very high but with some regional variations, the concentrations in Pocheon, Wonju, Chungju, Jecheon, Yeongju areas were over 0.014 ppm, much higher than in other cities. The SO_2 concentration in summer was relatively low due to a large amount of rainfall. As shown in Fig. 2(e), annual SO_2 concentration are in the range of 0.002~0.010 ppm, and were higher than in northern areas of Gyeongbuk and Gyeonggi

Average annual SO_2 concentrations from 1999 to 2009 in major cities of Korea were shown in Fig. 3. In 1999, SO_2 concentration decreased in the order; Ulsan > Busan > Daegu > Daejeon > Seoul area and in 2009, the concentration in Ulsan was 0.008 ppm and 0.005 ppm in other cities. From 1999, Annual SO_2 concentrations was shown to decrease with time, and the concentrations in major cities were below the national air quality standard.

Fig. 4 shows the NO_2 concentration map for spring (a), summer (b), autumn (c), winter (d) and annual average (e) in the Korean Peninsula in 2009. The NO_2 concentrations were lowest in summer. Expecially the concentration in winter was very high but with some regional variations. The concentration were higher, over 0.040 ppm in Seoul, Suwon, Seongnam, Gwangmyeong areas than others. The NO_2 concentration in summer was relatively low due to a large amount of rainfall. As shown in Fig. 4(e), annual NO_2 concentration is in the range of 0.006~0.039 ppm, higher in metropolitan areas.

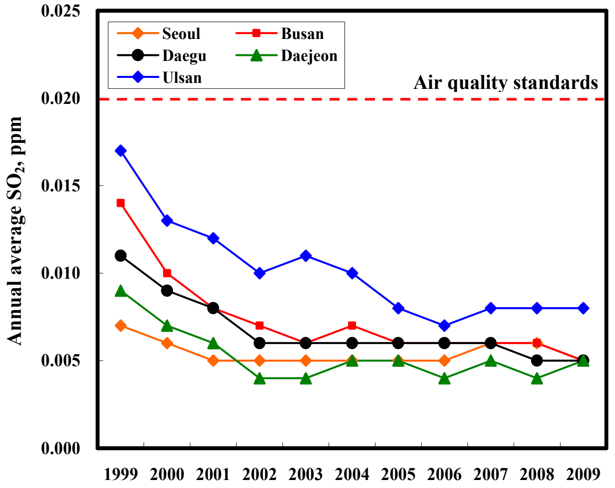


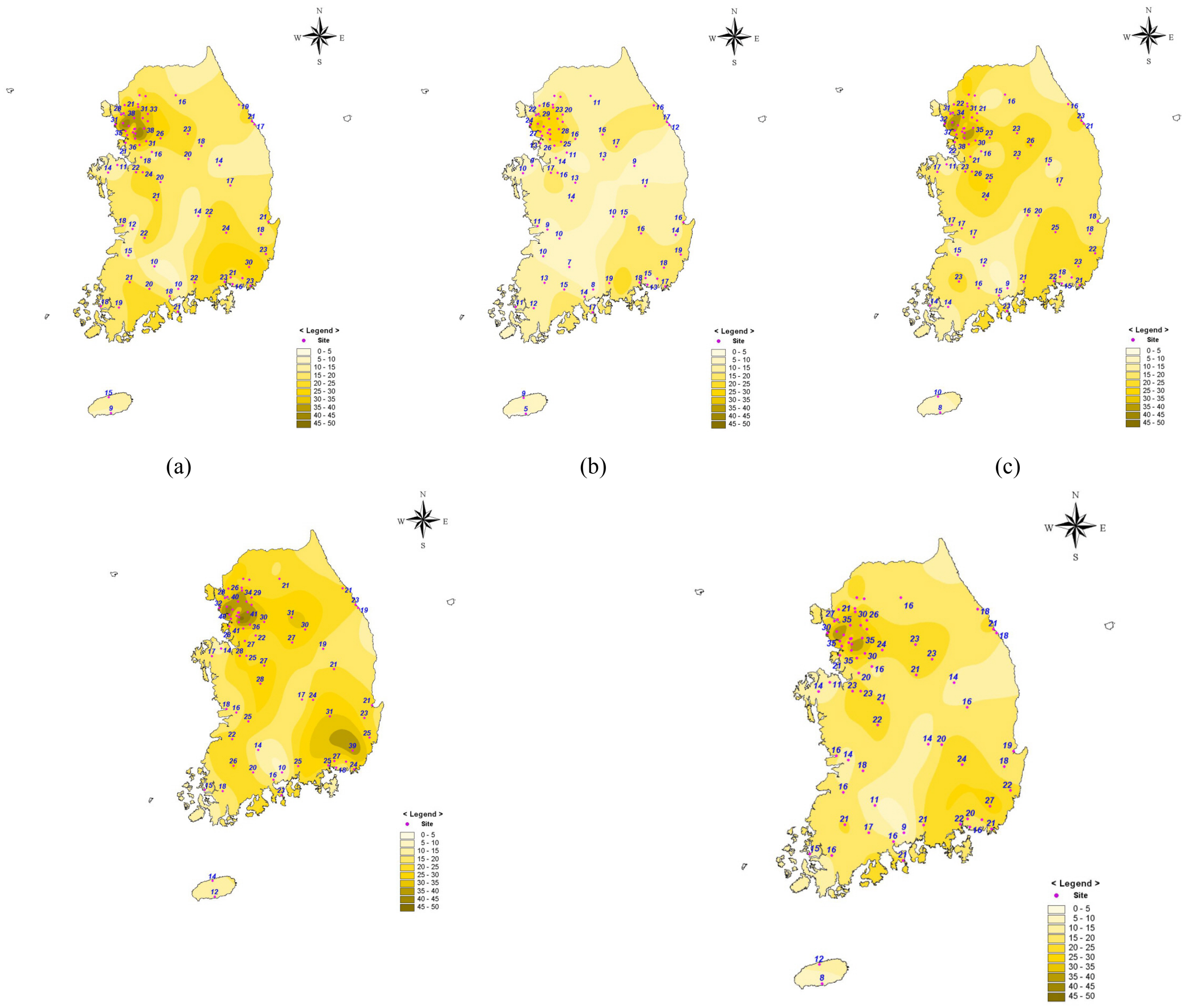
Fig. 3. Annual average sulfur dioxide(SO_2) concentration of major cities from 1999 to 2009.

Annual average NO_2 concentrations from 1999 to 2009 of major cities in Korea were shown in Fig. 5. From 1999 to 2009, NO_2 concentration has not varied much over years, and the concentration in Seoul has been over air quality standard. In 2009, the concentration in Seoul was 0.035 ppm and below 0.030 ppm in other cities.

3.2 Atmospheric corrosivity by environmental factors

Fig. 6 shows TOW maps for 10 years(2001~2010) in spring (a), summer (b), autumn (c), winter (d) and annual average (e) in the Korean Peninsula. As discussed in the above, average annual rainfall was 500~1500 mm with rainfall concentrated in summer. Relative humidity is over 80 % in July and August, and it is near 70 % in September and October. In spring, TOW belongs to category τ_4 in part of western and southern coast areas and τ_3 in other coast areas. In summer, TOW was highest, falling in category τ_5 in Daegwanryeong, Mokpo, Heuksando, Jindo, Jejudo areas and τ_4 in the other cities. In autumn, TOW belongs to category τ_3 in Seoul, Gangneung, Incheon, Ulsan, Pohang areas and τ_4 in the others. In winter, TOW falls in category τ_3 in all areas. In summary, average annual TOW was high, falling in the range of category τ_3 to τ_4. It is τ_4 in coastal areas and decreases to τ_3 with the distance from the sea.

Table 1 shows the deposition rate and classes of sulfur dioxide and chloride determined by ISO 9223 in 2007. The data are plotted in Fig. 7 for the deposition rate and corrosion class of sulfur dioxide and in Fig. 8 for the depo-



(a) (b) (c)

(d) (e)

Fig. 4. NO_2 concentration map; (a) spring, (b) summer, (c) autumn, (d) winter, and (e) annual average of the Korean Peninsula at 2009. (unit: ppb)

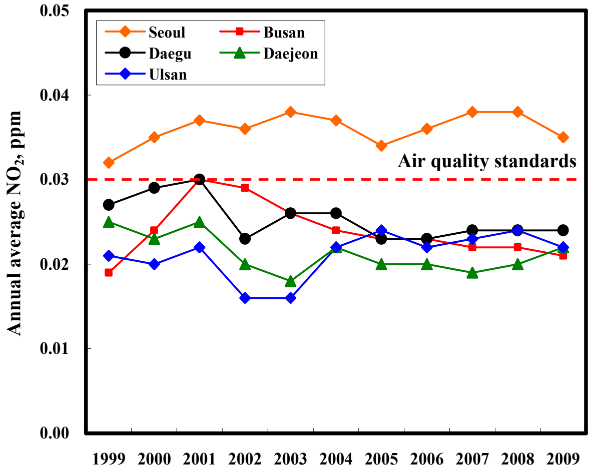
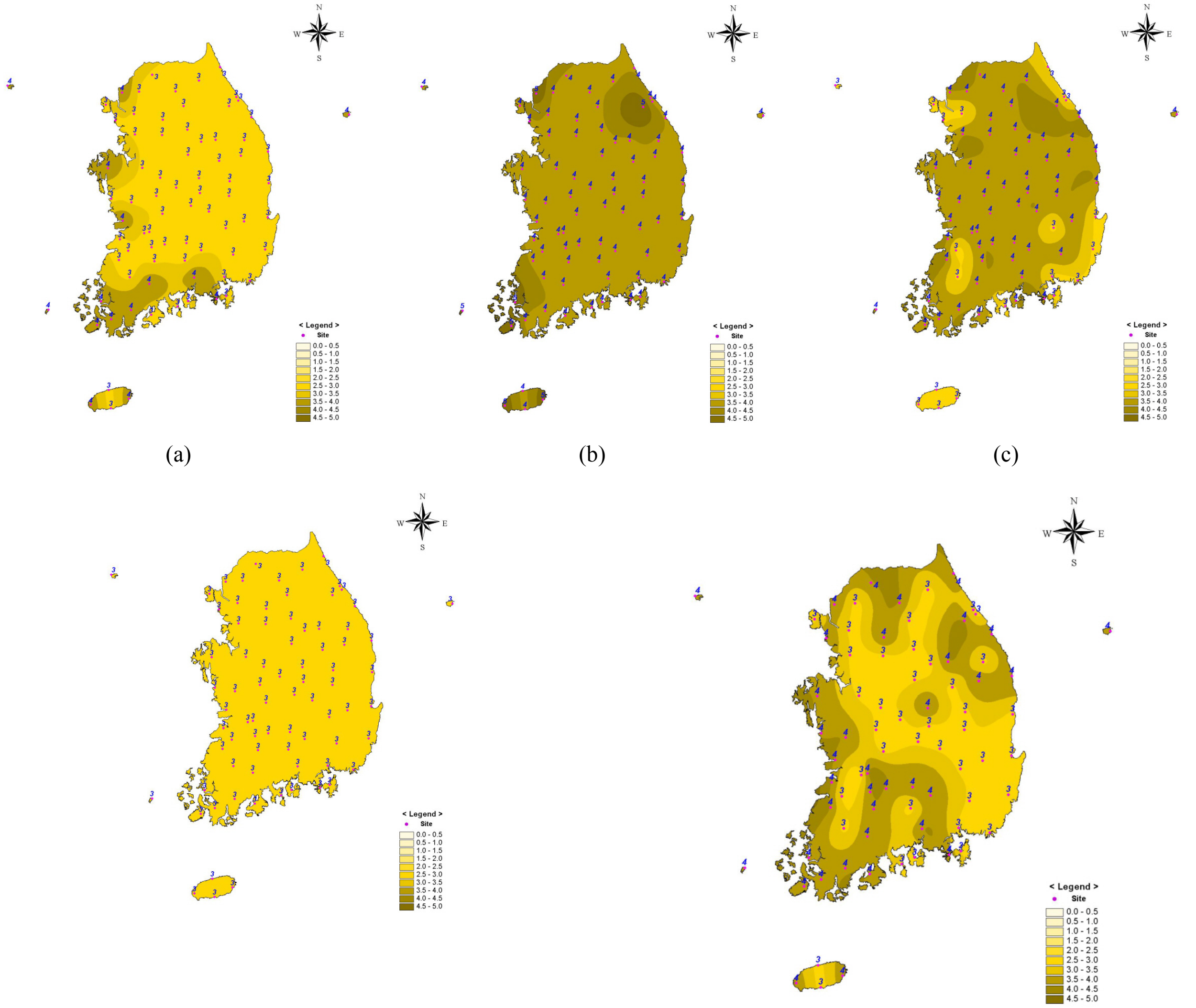


Fig. 5. Annual average nitrogen dioxide(NO_2) concentration of major cities from 1999 to 2009.

sition rate and corrosion class of chloride. Deposition rates of sulfur dioxide were around 5 $mg/m^2\cdot day$, and corrosivity category classified by SO_2 deposition rate is P_0. However, the deposition rate was 25.8 $mg/m^2\cdot day$ in Ulsan, a typical industrial zone, corresponding to corrosivity category, P_1. The rate of chloride deposition was about 1 $mg/m^2\cdot day$ in all areas falling in corrosivity category S_0 except in Wolpo, Ulsan, Shinchon in which the deposition rate were 40.9, 6.0 and 4.0 $mg/m^2\cdot day$, respectively, belonging to corrosivity category S_1.

Table 2 summarizes the corrosivity categories of carbon steel, zinc, copper and aluminium classified by sulfur dioxide, chloride deposition, and TOW in 2007. Corrosivity categories in all test sites classified by SO_2 deposition rate, chloride deposition rate, and TOW were P_0~P_1, S_0~S_1 and



(a) (b) (c)

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Fig. 6. TOW class map on the base of 10 years(2001~2010) average value ; (a) spring, (b) summer, (c) autumn, (d) winter, and (e) average.

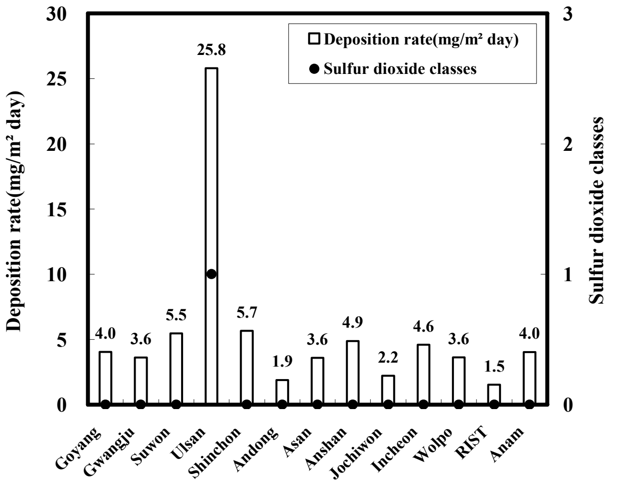

Fig. 7. Deposition rate and corrosion class of sulfur dioxide determined by ISO 9223.

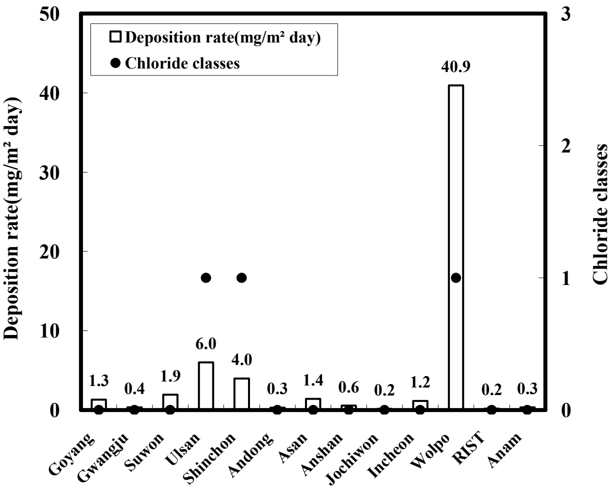

Fig. 8. Deposition rate and corrosion class of chloride.

Table 1. Deposition rate and classes of sulfur dioxide and chloride determined by ISO 9223

Sites	SO_2		Cl^-	
	Deposition rate (mg·m^{-2}·day^{-1})	Class	Deposition rate (mg·m^{-2}·day^{-1})	Class
Goyang	4.0	P_0	1.3	S_0
Gwangju	3.6	P_0	0.4	S_0
Suwon	5.5	P_0	1.9	S_0
Ulsan	25.8	P_1	6.0	S_1
Seoul-Shinchon	5.7	P_0	4.0	S_1
Andong	1.9	P_0	0.3	S_0
Asan	3.6	P_0	1.4	S_0
Anshan	4.9	P_0	0.6	S_0
Jochiwon	2.2	P_0	0.2	S_0
Incheon	4.6	P_0	1.2	S_0
Pohang-Wolpo	3.6	P_0	40.9	S_1
Pohang-RIST	1.5	P_0	0.2	S_0
Seoul-Anam	4.0	P_0	0.3	S_0

Table 2. Corrosivity classes of carbon steels, zinc, copper and aluminum by TOW, sulfur dioxide and chloride

Sites	Environmental Class			Corrosivity Class		
	SO_2	Cl^-	TOW	Carbon steels	Zinc & Copper	Alu-minum
Goyang	P_0	S_0	τ_3	C2-C3	C3	C3
Gwangju	P_0	S_0	τ_3	C2-C3	C3	C3
Suwon	P_0	S_0	τ_3	C2-C3	C3	C3
Ulsan	P_1	S_1	τ_3	C2-C3	C3	C3
Seoul-Shinchon	P_0	S_1	τ_3	C2-C3	C3	C3
Andong	P_0	S_0	τ_3	C2-C3	C3	C3
Asan	P_0	S_0	τ_3	C2-C3	C3	C3
Anshan	P_0	S_0	τ_3	C2-C3	C3	C3
Jochiwon	P_0	S_0	τ_3	C2-C3	C3	C3
Incheon	P_0	S_0	τ_4	C3	C3	C3
Pohang-Wolpo	P_0	S_1	τ_4	C3	C3	C3
Pohang-RIST	P_0	S_0	τ_3	C2-C3	C3	C3
Seoul-Anam	P_0	S_0	τ_3	C2-C3	C3	C3

τ_3~τ_4, respectively. That is, corrosivity categories classified by SO_2 and chloride deposition rate were low, but high classified by TOW in Korean Peninsula. On the basis of these data, corrosivity of atmospheres classified by corrosion rate in carbon steel, zinc, copper, aluminium are low-medium, C2-C3 and medium, C3 in zinc, copper, and aluminium as in Fig. 9.

4. Conclusions

1) Average annual pH values of rain were in the range of 4.5~5.5 in Korean Peninsula from 1999 to 2009 and relatively lower in coastal areas. Average annual SO_2 concentrations have been decreased with time for the period, and its concentrations in major cities were below the national air quality standard, but NO_2 concentration has not varied much over the years, and its concentration in Seoul has been over the national air quality standard.

2) In 2007, corrosivity categories classified by SO_2 deposition rate, chloride deposition rate, and TOW were P_0~P_1, S_0~S_1 and τ_3~τ_4, respectively. That is, corrosivity categories classified by SO_2 and chloride deposition rate were low, but high classified by TOW in Korean Peninsula. On the basis of these environmental categories, corrosivity of atmospheres classified by corrosion rate in carbon steel, zinc, copper, aluminium are low-medium, C2-C3 and medium, C3 in zinc, copper, and aluminium.

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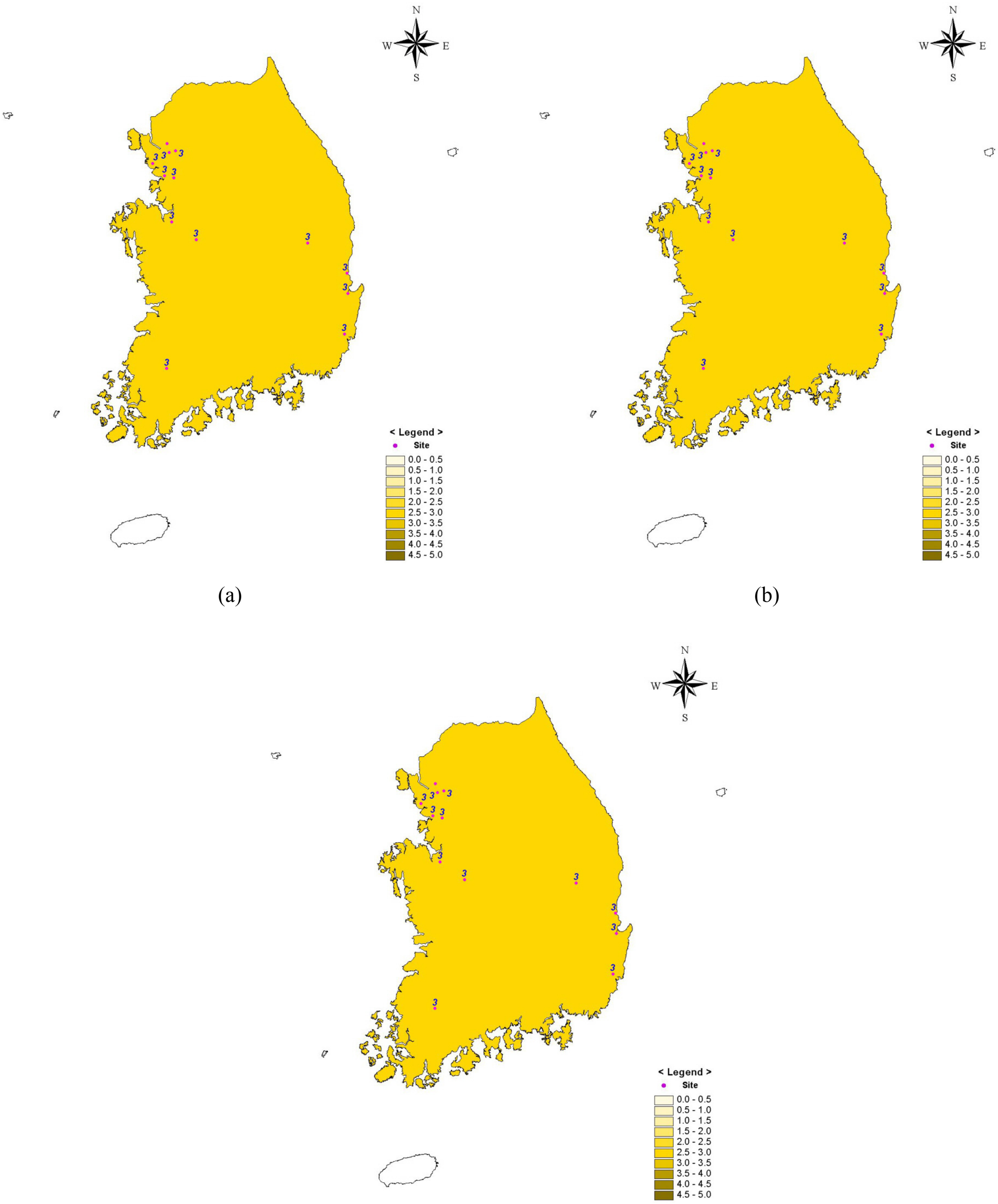

(a) (b)

(c)

Fig. 9. Atmospheric corrosivity map of metals based on ISO environmental factors(TOW, SO_2, chloride); (a) carbon steel, (b) zinc & copper, (c) aluminum.

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