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Fourth Periodic Report on the State of Acid Deposition in East Asia

Part II : National Assessment

Cambodia
China
Indonesia
Japan
Lao PDR
Malaysia
Mongolia
Myanmar
Philippines
Republic of Korea
Russia
Thailand
Vietnam

Acid Deposition Monitoring Network in East Asia (EANET)

The Fourth Periodic Report
on the State of Acid Deposition in East Asia

Part II: National Assessment

Edited by:

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Preface

This report is the National Assessment, Part II of Fourth Periodic Report on the State of Acid Deposition in East Asia (PRSAD4). The National Assessment of PRSAD4 was prepared by each participating country according to the format for national assessment that prepared by the Drafting Committee of the PRSAD4. At present, thirteen countries, namely Cambodia, China, Indonesia, Japan, Lao PDR, Malaysia, Mongolia, Myanmar, Philippines, Republic of Korea, Russia, Thailand, and Vietnam have participated in the EANET. Those countries have shared the progress of their national monitoring activities, including state of acid deposition and air pollution in their respective country and the national measures implemented. In this report, basic information on national monitoring activities including quality assurance and quality control (QA/QC) for monitoring data as well as state of acid deposition and air pollution are introduced and evaluated for participating countries of EANET. Monitoring data obtained by the EANET activities in each participating country in 2015-2019 were utilized for evaluating the current status and impact of the acid deposition and air pollution in the EANET region. This report also includes the long-term analysis of the temporal trend and variation of acid deposition and air pollution in each country based on the twenty-year monitoring data from 2000 to 2019. Additionally, other national and international monitoring results are also introduced as references for assessment to interpretate EANET activities in each participating country.

Not surprisingly, since the status of acid deposition and air pollution in individual participating countries is closely related to the status of the entire East Asian region, regular analysis of the relationship between them is important for predicting a future environmental pollution in that region. We hope that the Regional Assessment Report and National Assessment Report created this time will help you to understand the relationship between East Asian countries and the entire EANET region.

National Assessment on Acid Deposition in Cambodia

Chapter 1. Base Information on National Monitoring Activities

1.1 Outline of the activities on acid deposition and National Monitoring Plan

The acid deposition is regarded as a global issue and has been highly concerning in many regions in the world. Therefore, Cambodia participated in Acid Deposition Monitoring Network in East Asia (EANET) in 2001 and implemented regular monitoring activities together with twelve other countries. The national monitoring plan developed in 2006 for wet deposition monitoring, dry deposition monitoring has started from February 2010 and the monitoring of inland aquatic environment has started from June 2011.

1.2 Monitoring Station

Sites	Charac-teristics	Latitude	Longitude	Altitude
Phnom Penh Dry	**Urban**	**11°33'17"944 N**	**104°56'19"168 E**	15 m
Phnom Penh Wet	**Urban**	**11°33'17"944 N**	**104°56'19"168 E**	15 m
Phnom Penh PM 2.5	**Urban**	**11°33'17"944 N**	**104°56'19"168 E**	15 m
Phnom Penh Ozone (O_3)	**Urban**	**11°33'17"944 N**	**104°56'19"168 E**	15 m
Siem Reap (Wet)	**Urban**	**13° 37' 55.27" N**	**103° 89' 30.76"E**	**17m**
Sras Srang Kirirom Inland	**Remote**	**11° 19' 41.83" N**	**104° 2' 13.30" E**	**800m**

1.2.1 Wet Deposition

Wet deposition monitoring uses automatic rain sampler.
Sampling frequency: weekly, Measurement of parameters (Method): pH (by pH meter), EC (by Electric Conductivity meter), SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} (by Ion Chromatography)

Sample amount, conductivity and pH should be measured as soon as possible after sample arrival, and checking agreement of samples and sample list. After conductivity and pH measurement, all samples should be filtered with clean membrane filters (pore size: 0.45μm). Filters should be well washed and be free from contamination. After filtration, samples should be refrigerated at 4ºC.

Effort should be made to start analysis of the other parameters within a week of sample arrival in the laboratory and to complete the data sets by measuring EC, pH and all other chemical parameters.

1.2.2 Dry Deposition

Cambodia was installed dry deposition monitoring in February 2010 in Phnom Penh city (11° 33' N, 104° 55' E). Used the four-stage filter pack method, Filter pack method is available for the measurement of SO_2, HNO_3, HCl, NH_3, and particulate component (SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}). The four-stage filter pack method can measure all of these parameters at the same time. Sampling intervals: Every two weeks, Procedure: 1. Preparation of filter pack, 2. Sampling, 3. Extraction and chemical analysis, 4. Calculation of results.

Stage	Reaction	Collected specie
1st (F0)	Filtration	Aerosols SO_4^{2-}, NO_3^-, Cl^-, Na^+, NH_4^+, K^+, Ca^{2+}, Mg^{2+}
2nd (F1)	Adsorption	HNO_3, partial SO_2, partial HCl SO_4^{2-},NO_3^-,Cl^-, NH_4^+
	Neutralization by collected acid gases	partial NH_3
3rd (F2)	Neutralization by alkali impregnated cellulose filter	SO_2, HCl, SO_4^{2-}, Cl^-
4th (F3)	Neutralization by acid impregnated cellulose filter	NH_3, NH_4^+

1.2.3 Inland Aquatic Environment Monitoring

Cambodia has started monitor inland aquatic environment from June 2011, named SRAS SRANG at KIRIRUM National Park, Kampong Speu Province, about 110 km from Phnom Penh city (11º 19' N104º 03' E), water sample take 2 times a year, monitoring items: Temperature, Alkalinity, pH, EC, SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}.

Figure 1.2.3.1. Pictures of inland aquatic environment.

1.2.4 PM2.5 Monitoring

Cambodia has started monitoring PM2.5 from April 2017.

Figure 1.2.4.1. Picture of PM2.5 Monitoring.

1.2.5 Ozone (O_3) Monitoring

Cambodia has started monitoring Ozone (O_3) from August 2019.

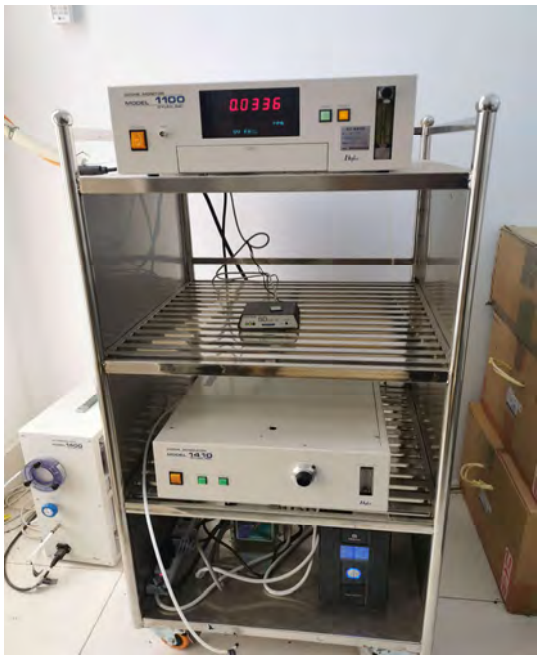


Figure 1.2.5.1. Picture of Ozone (O_3) Monitor.

Chapter 2. State of Acid Deposition in Cambodia

2.1 State of wet deposition

Rapidly growth of industrialization and urbanization in certain areas, Cambodia has brought about air pollution problem from factories and motor vehicles emit harmful gases such as CO, NOx, SO_2 and Particulates Matter (PM).

Although the overall air quality in the country is generally good, but air pollution is still concern.

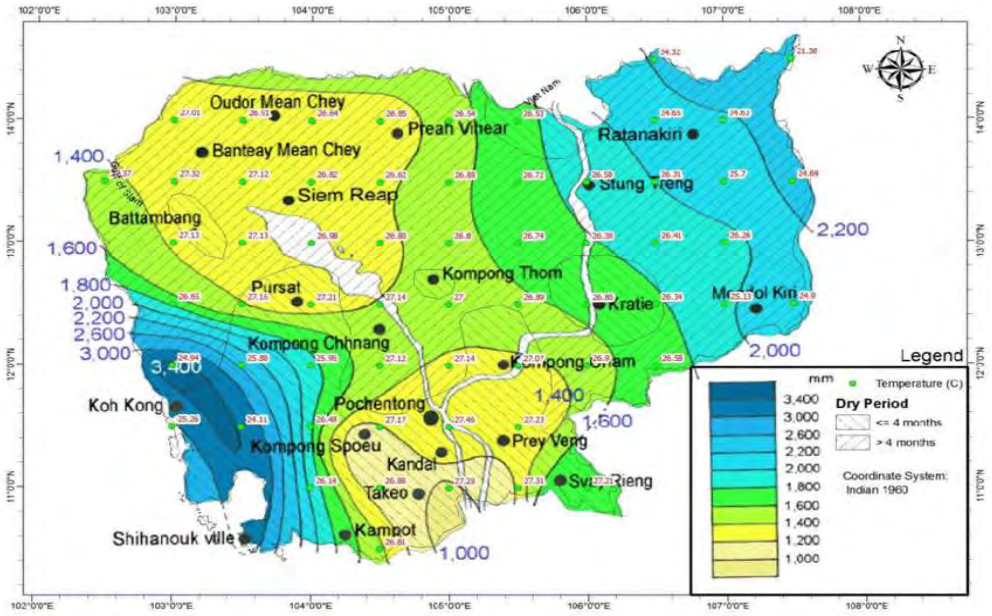


Figure 2.1.1. Average precipitation of all provinces in Cambodia (mm).

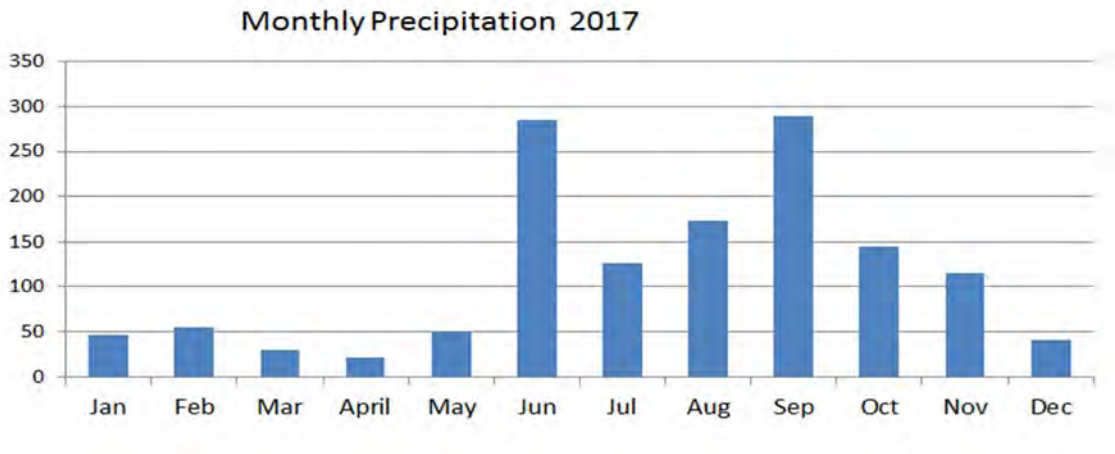


Figure 2.1.2. Monthly precipitation 2017 in Phnom Penh (mm).

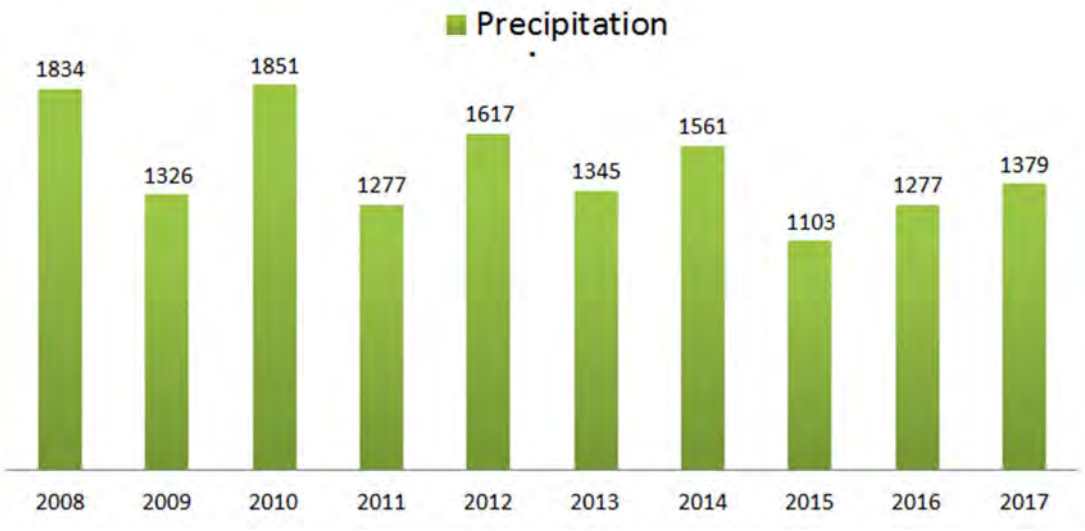


Figure 2.1.3. Yearly precipitation in Phnom Penh 2008-2017 (mm).

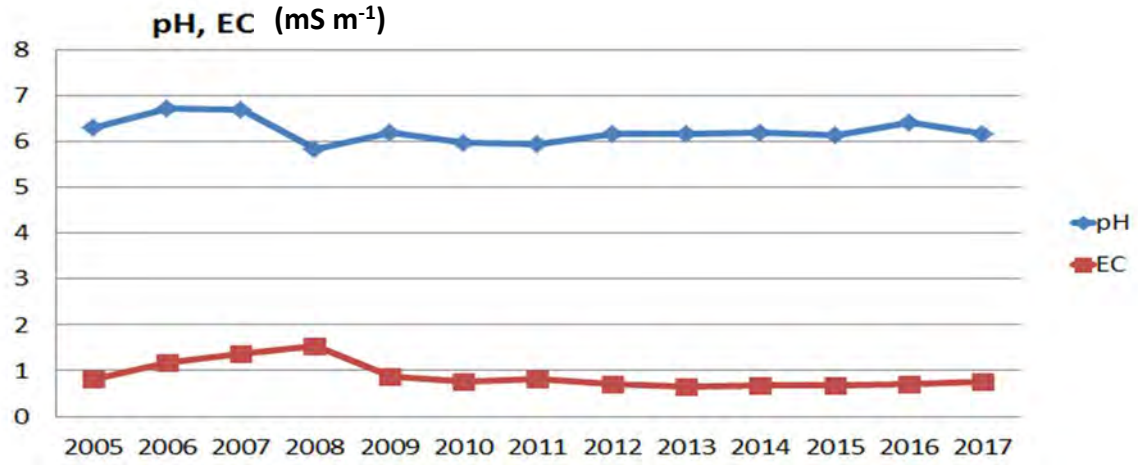


Figure 2.1.4. Yearly Concentrations of pH and EC for Wet deposition.

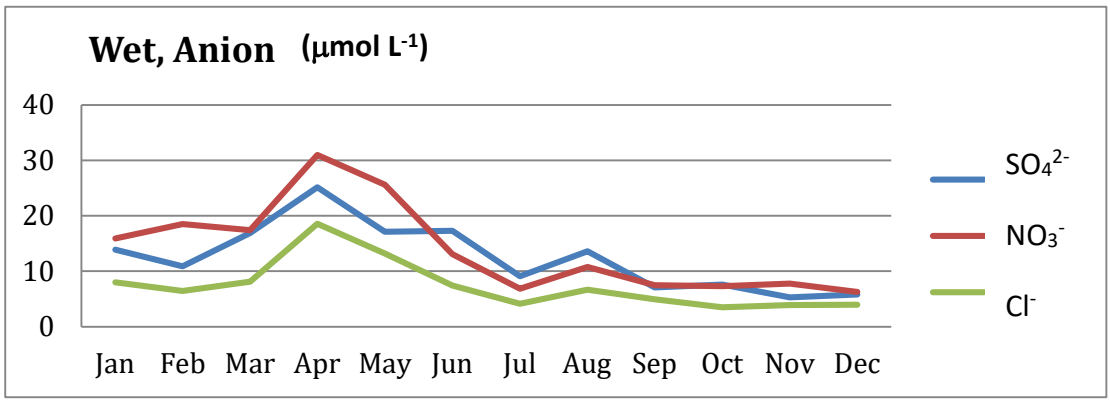


Figure 2.1.5. Monthly Concentrations of Anion in 2017.

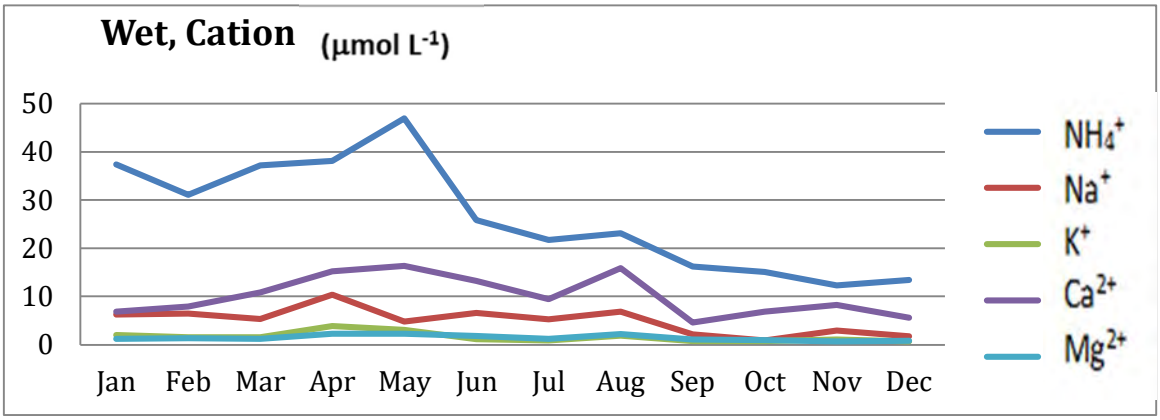
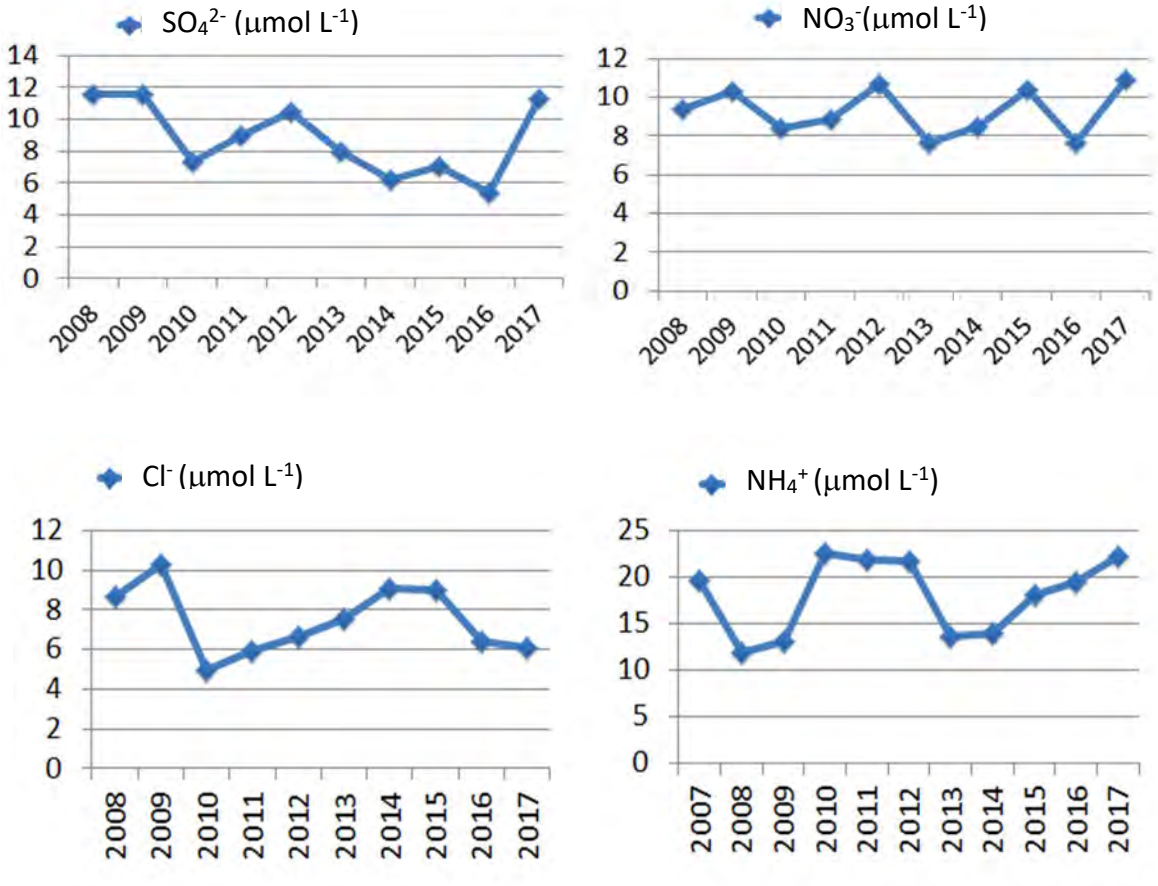


Figure 2.1.6. Monthly Concentrations of Cation in 2017.



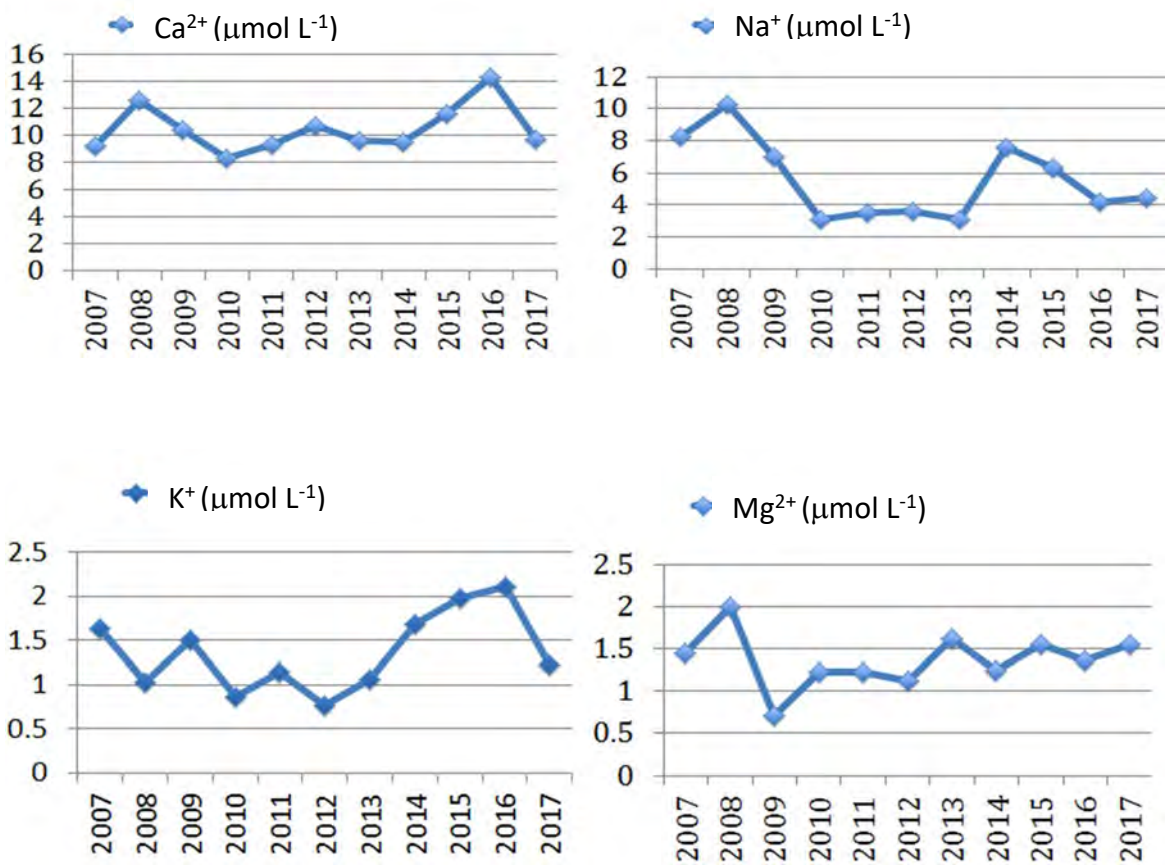


Figure 2.1.7. Yearly Concentrations of Anion and Cation, Wet deposition.

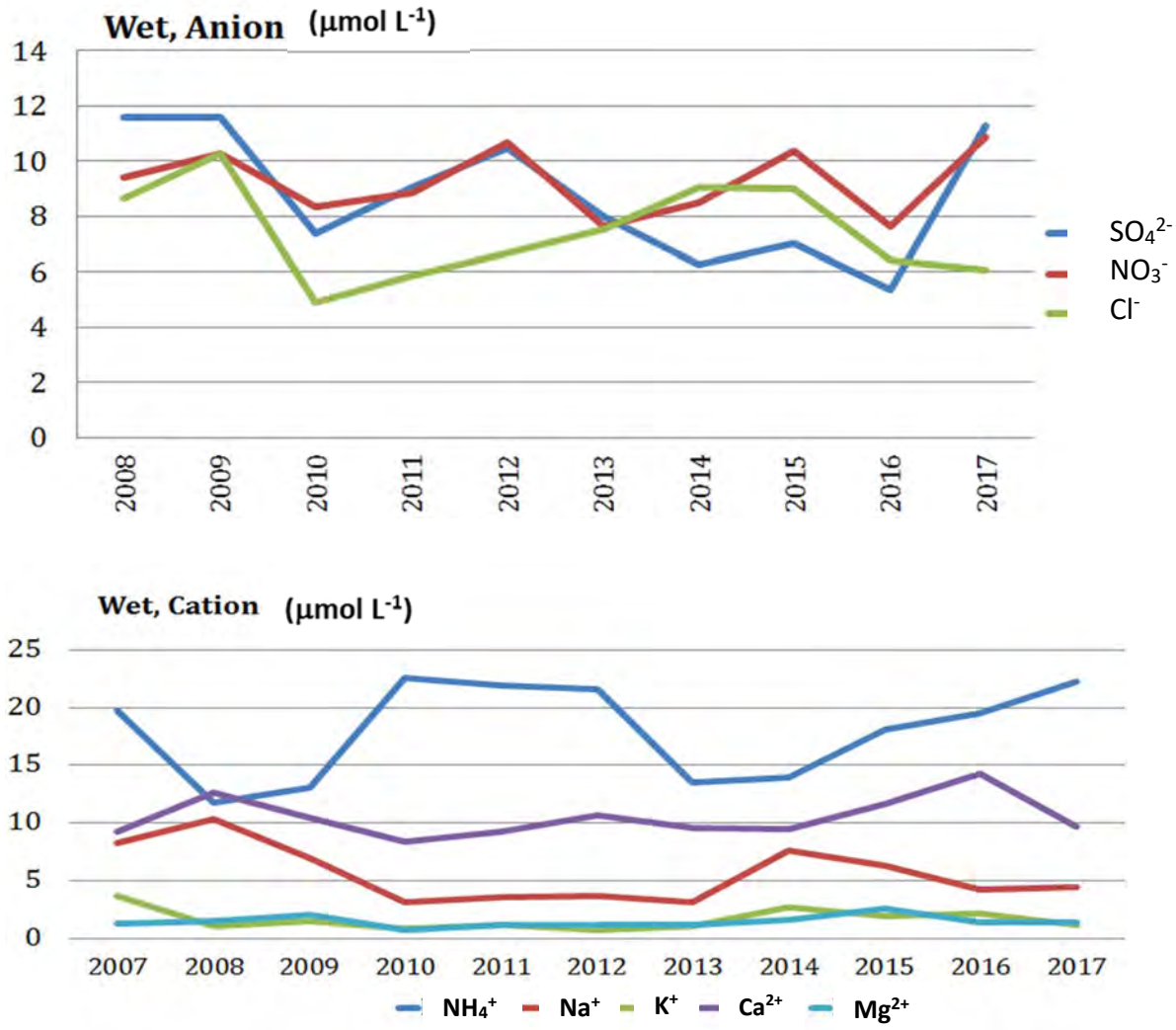


Figure 2.1.8. Yearly Concentrations of Wet deposition.

2.2 State of dry deposition

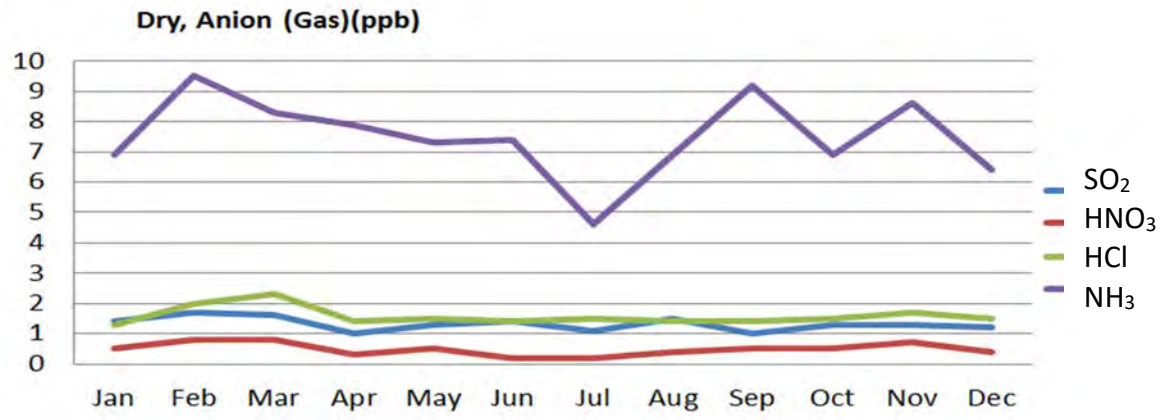


Figure 2.2.1. Monthly Concentrations of Anion (gas) for dry in 2017.

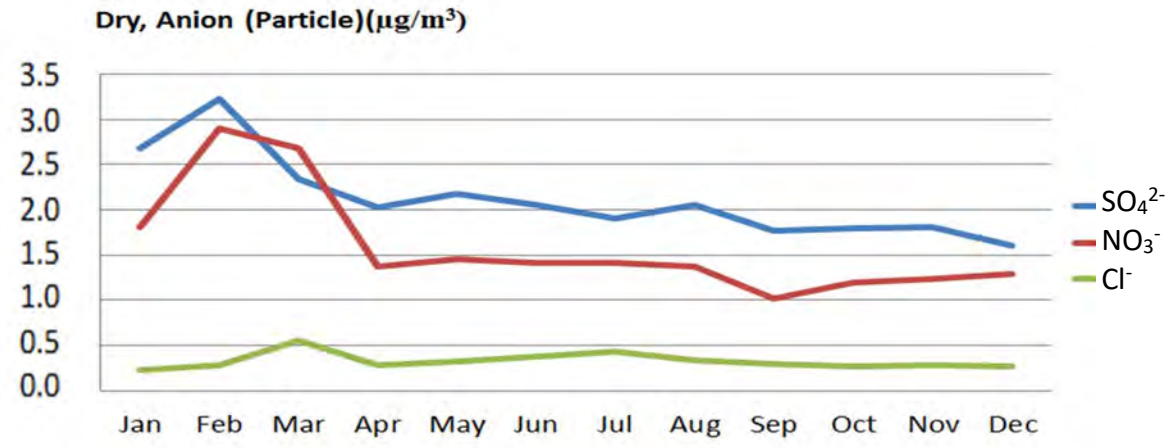


Figure 2.2.2. Monthly Concentrations of Anion (Particle) for dry in 2017.

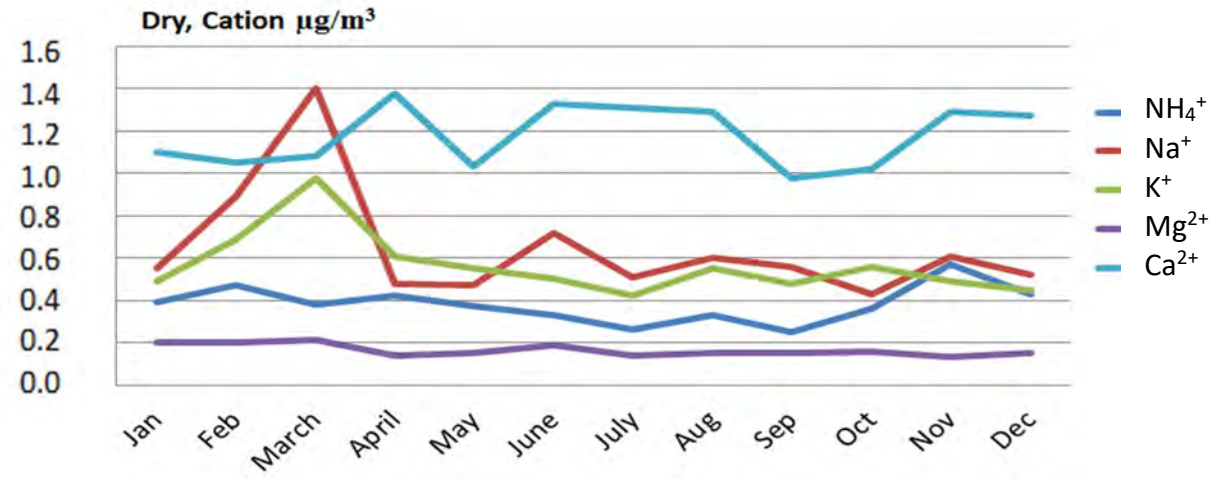
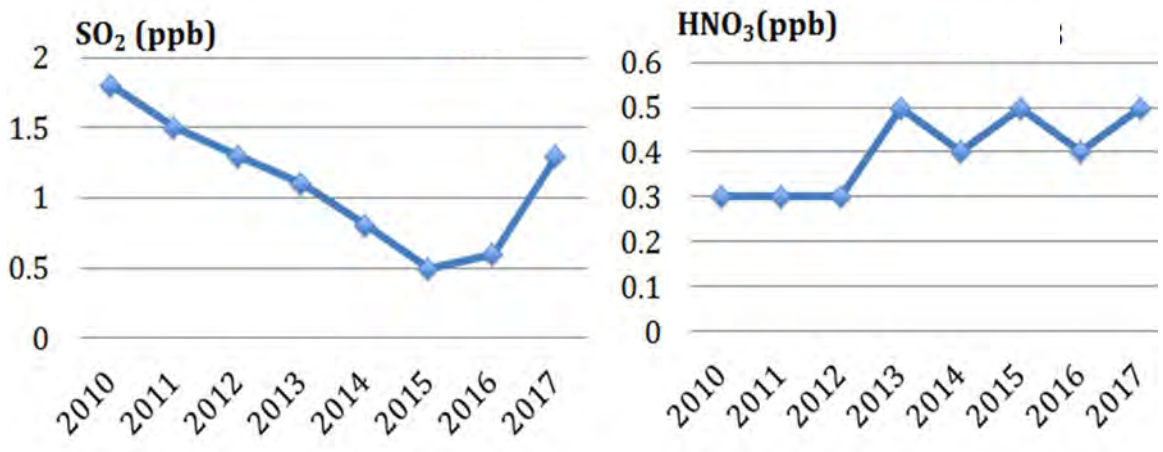
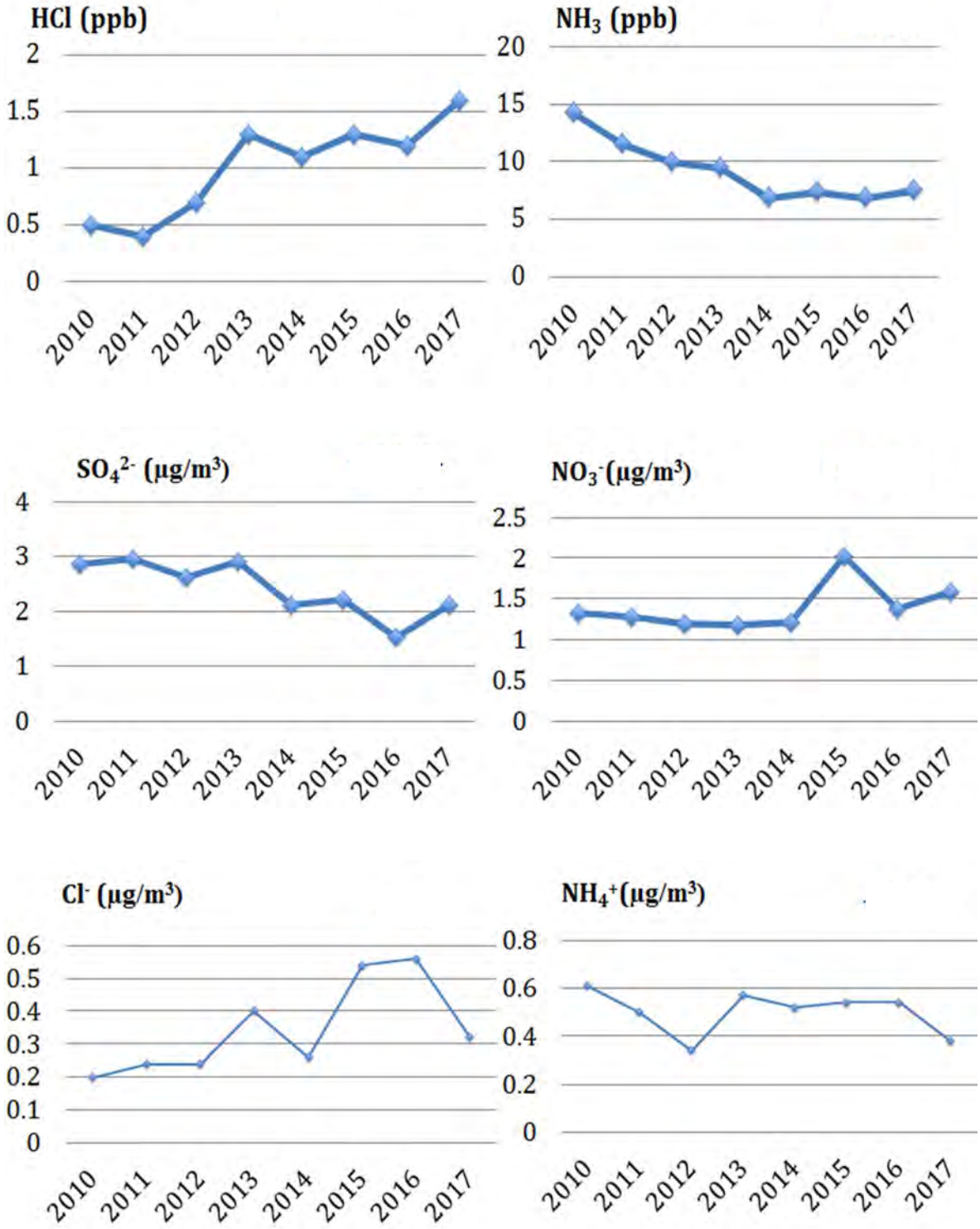


Figure 2.2.3. Monthly Concentrations of Cation (Particle) for dry in 2017.




HCl (ppb)
2
1.5
1
0.5
0
2010
2011
2012
2013
2014
2015
2016
2017
NH3 (ppb)
20
15
10
5
0
2010
2011
2012
2013
2014
2015
2016
2017
SO4 2- (µg/m3)
4
3
2
1
0
2010
2011
2012
2013
2014
2015
2016
2017
NO3 -(µg/m3)
2.5
2
1.5
1
0.5
0
2010
2011
2012
2013
2014
2015
2016
2017
Cl- (µg/m3)
0.6
0.5
0.4
0.3
0.2
0.1
0
2010
2011
2012
2013
2014
2015
2016
2017
NH4 +(µg/m3)
0.8
0.6
0.4
0.2
0
2010
2011
2012
2013
2014
2015
2016
2017

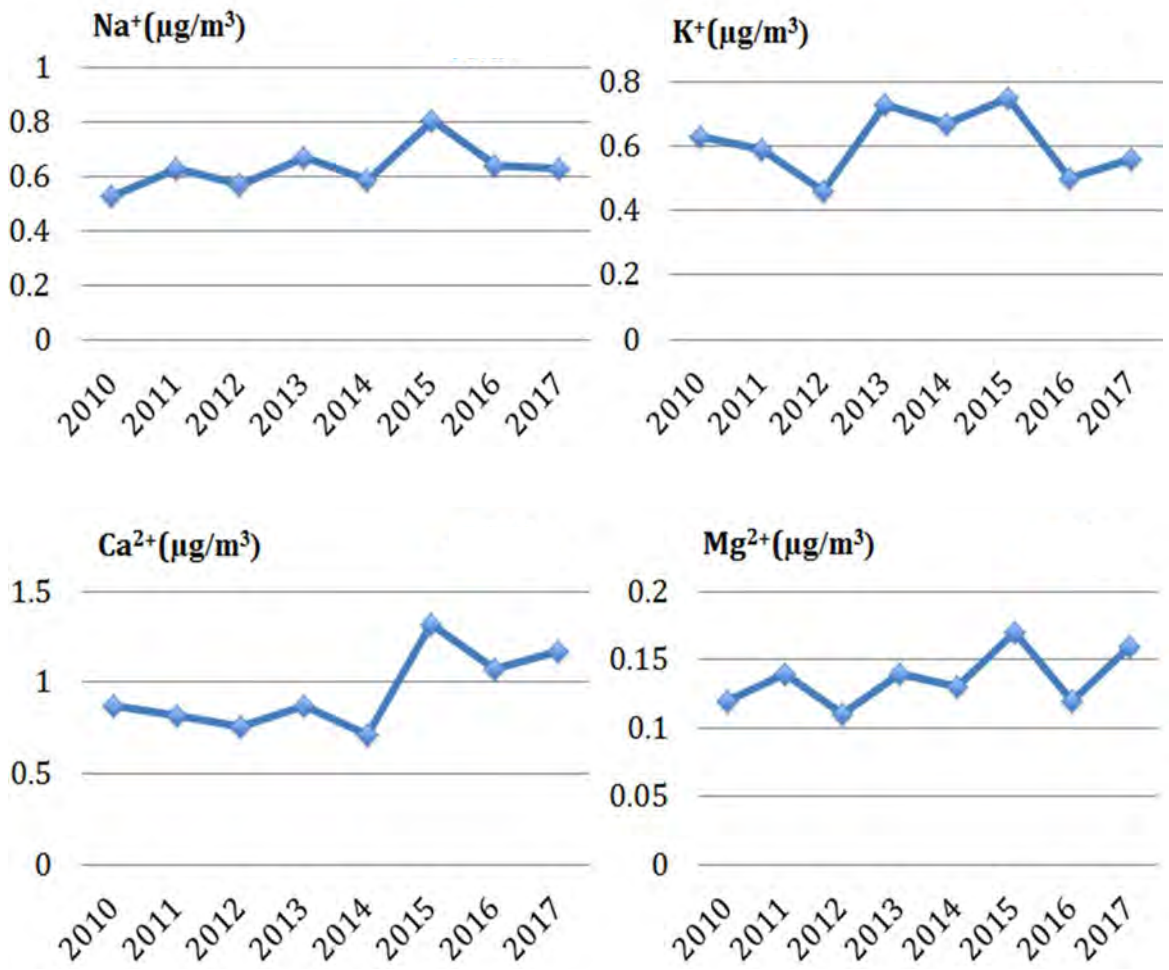


Figure 2.2.4. Yearly Concentrations of Anion and Cation for dry from 2010 to 2017.

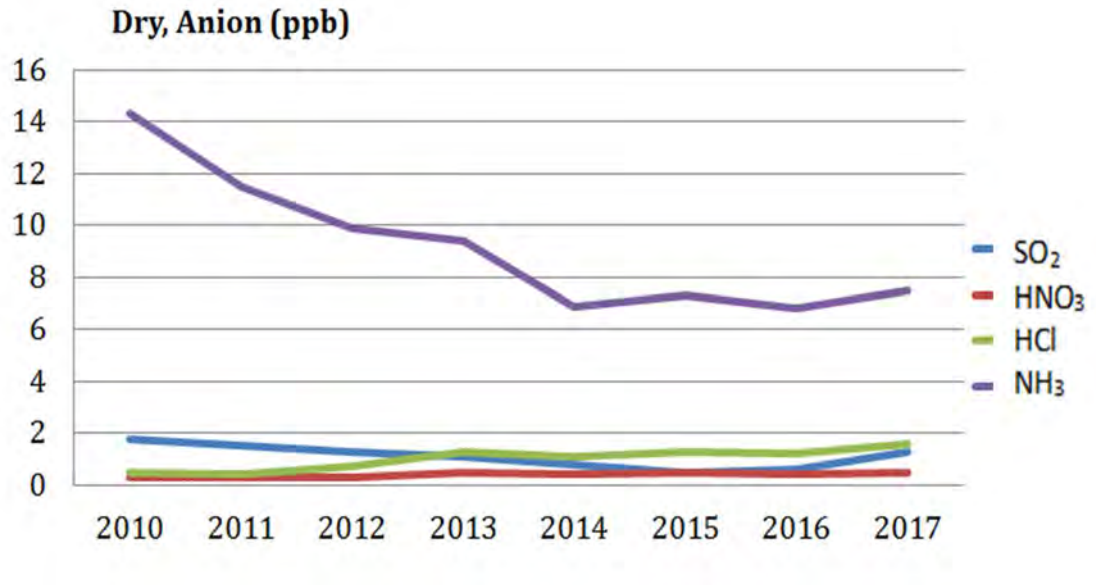


Figure 2.2.5. Yearly Concentrations of Anion (gas) for dry from 2010 to 2017.

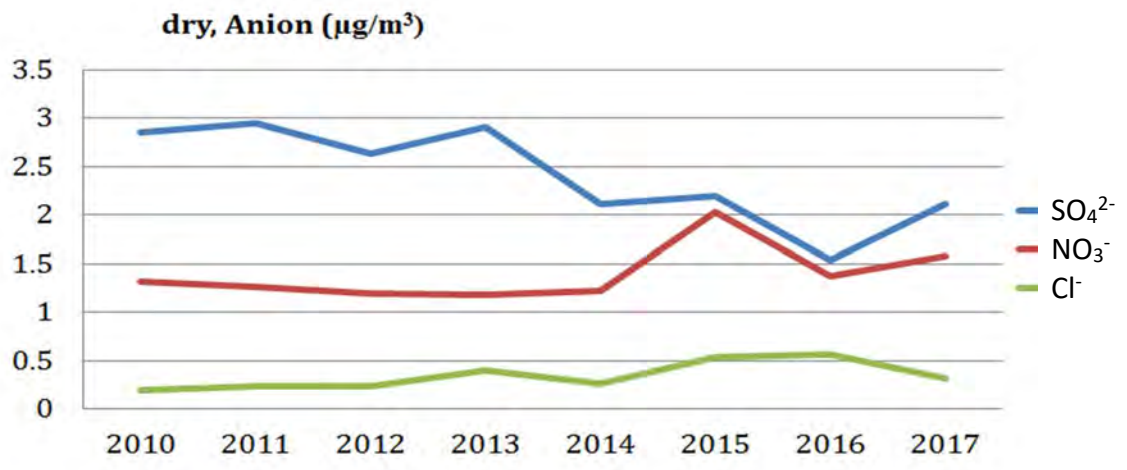


Figure 2.2.6. Yearly Concentrations of Anion for dry from 2010 to 2017.

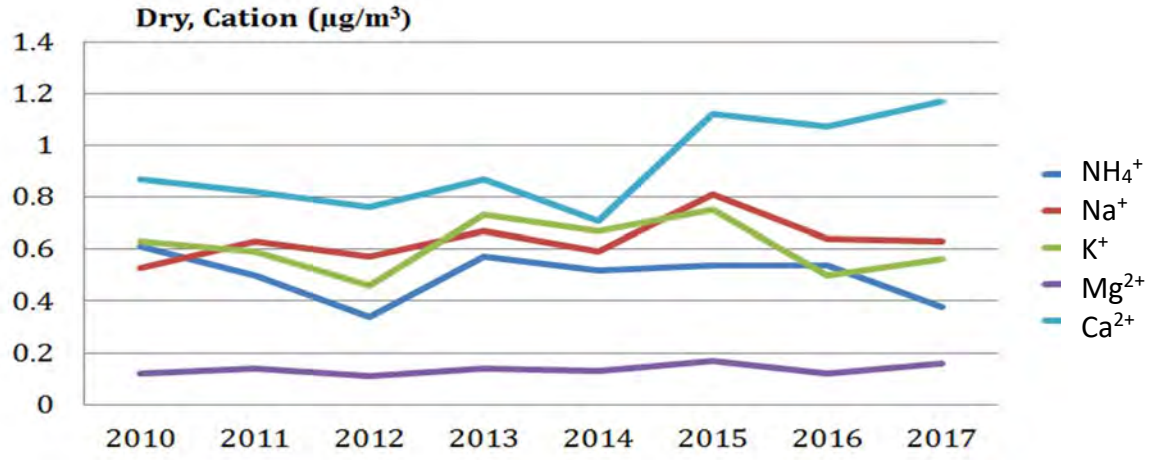


Figure 2.2.7. Yearly Concentrations of Cation for dry from 2010 to 2017.

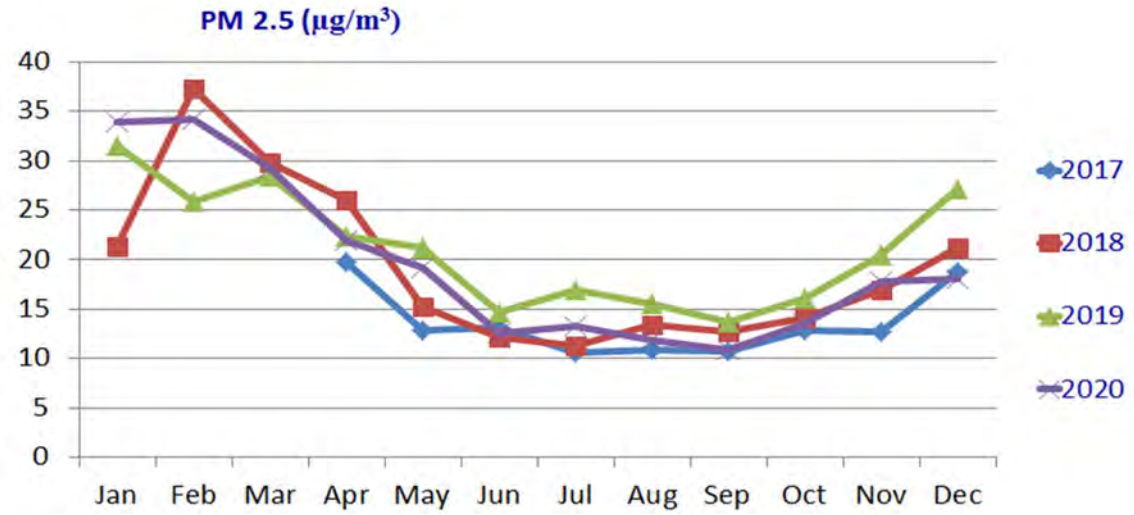


Figure 2.2.8. Monthly Concentrations of PM2.5.

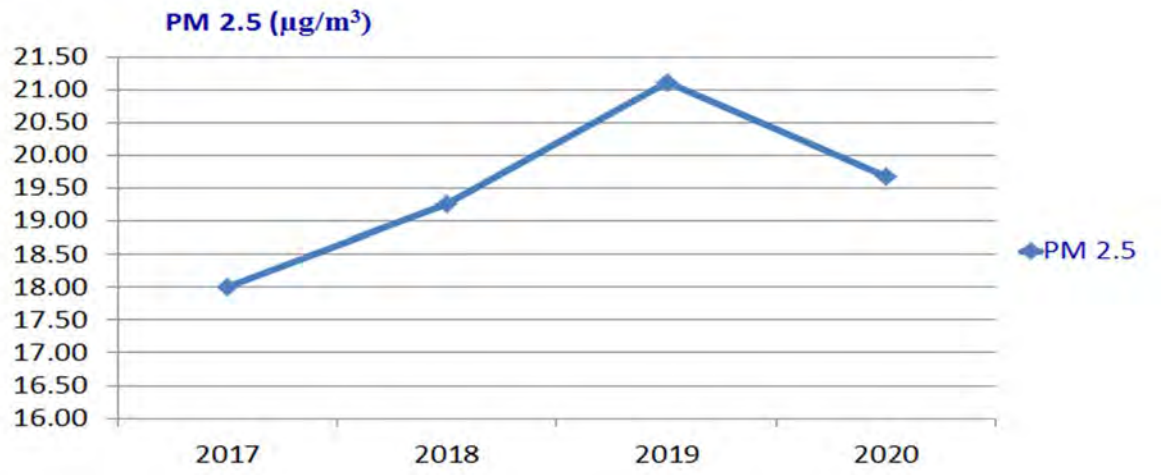


Figure 2.2.9. Yearly Concentrations of PM2.5.

2.3 State of Inland Aquatic Environment

Table 2.3.1 Concentrations of inland aquatic environment

Items	2012	2013	2014	2015	2016	2017
pH	6.46	5.74	5.84	5.81	5.95	6.04
EC	0.88	0.93	0.96	0.98	0.92	0.97
Alkalinity meq L^{-1}	0.04	0.03	0.04	0.04	0.03	0.03
SO_4^{2-} mg L^{-1}	0.08	0.05	0.06	0.09	0.10	0.07
NO_3^- mg L^{-1}	0.06	0.28	0.6	0.22	0.30	0.06
Cl^- mg L^{-1}	1.65	1.39	1.38	1.17	1.10	1.12
NH_4^+ mg L^{-1}	0.04	0.02	0.12	0.07	0.09	0.01
Na^+ mg L^{-1}	0.94	0.94	1.03	0.80	0.91	0.67
K^+ mg L^{-1}	0.13	0.12	0.31	0.19	0.14	0.08
Ca^{2+} mg L^{-1}	0.27	0.29	0.26	0.37	0.27	0.17
Mg^{2+} mg L^{-1}	0.16	0.13	0.12	0.22	0.13	0.09

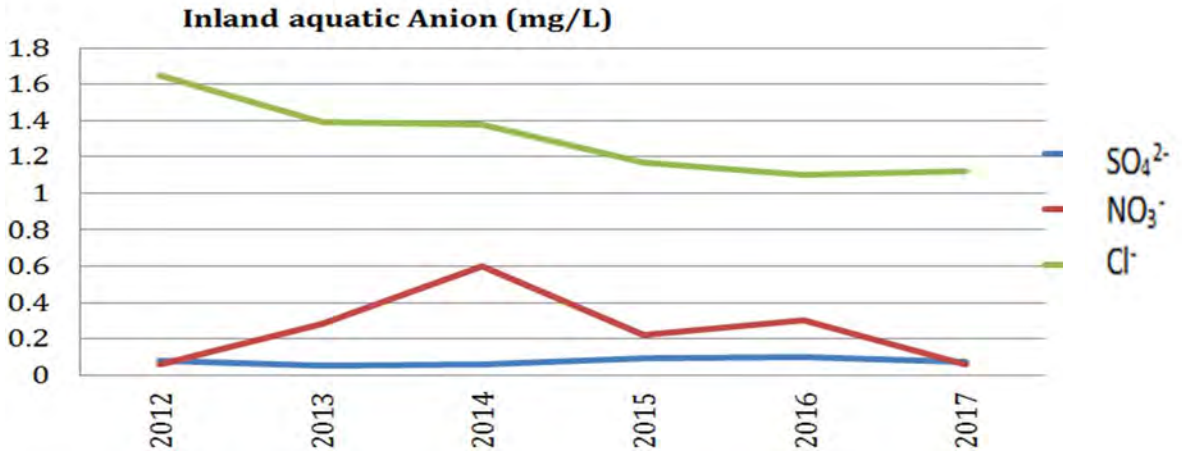


Figure 2.3.1. Yearly Concentrations of Anion for Inland Aquatic Environment.

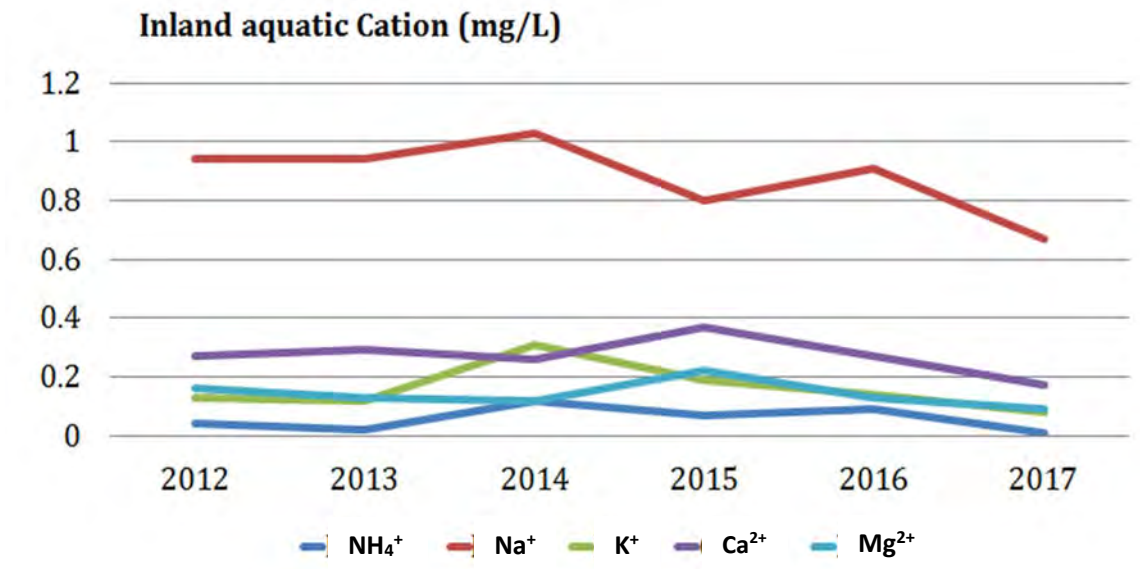


Figure 2.3.2. Yearly Concentrations of Cation for Inland Aquatic Environment.

2.4 Conclusion

Based on result of wet deposition, dry monitoring, inland aquatic environment, PM2.5 and O_3 Monitoring data from 2010-2018, the state of acid deposition and its negative impacts has not yet evidenced in Cambodia. However, air pollution in Cambodia is the major concern due to rapid growth of transportation, industrialization construction and open burning. Ministry of Environment is responsible for environmental protection in the whole country, especially air quality issue. Ministry of Environment in the process to prepare new regulation of air pollution control included air quality standards, emission standards, fuel quality standards and other related standards to protect air quality in Cambodia.

Periodic Report on the State of Acid Deposition in EANET China

China National Environmental Monitoring Center (CNEMC)

Data analysis: Wang xiaofei, Zhang yashuang, Chen chanjuan, Jiao congying, Xie shuyan, Wang shuai , Sun kang, Zhu jian, Meng xiaoxing, He Zhidong, Li qiufang, Li yinmei, Bai chuan, Yang chenyuan

Report summary: Wang xiaofei

Report audit: Tang guigang

Chapter 1 Overview of Acid Deposition Monitoring Activities

1.1 Outline of the Activities on Acid Deposition Monitoring and National Monitoring Plan

EANET is a monitoring network mainly aimed to monitor and understand the status and impact of acid deposition in East Asia. As one of EANET member countries, China has carried out continuous monitoring activities over acid deposition as required since its formal operation in 2001. China selected Chongqing, Xiamen, Xi'an and Zhuhai as participating cities of EANET to carry out monitoring on wet deposition, dry deposition, inland water, soil and vegetation. As national center of EANET, China National Environmental Monitoring Center (CNEMC) develops national monitoring plans each year according to EANET's technical guidelines, guides monitoring activities of EANET China, and review the monitoring data submitted by 4 cities.

Xiamen started dry deposition monitoring and studies by using filter pack method in 2007. Due to the failure of filter pack sampling device which could not be repaired in China, the monitoring activities have been stopped since 2017.

In 2019, two cities officially participated in the EANET, which were Wuzhishan and Lijiang respectively. These two monitoring sites were selected as EANET sites and carried out wet and dry deposition monitoring.

1.2 Monitoring Sites

Since the participation in EANET, most sites of EANET China can carry out ongoing monitoring, and only certain specific sites stop monitoring or are altered, for they fail to meet the standards of EANET due to surrounding environment changes. The information of monitoring sites in Chongqing, Xi'an, Xiamen, Zhuhai, Wuzhishan and Lijiang is presented in the following table. The monitoring sites are classified into 3 sub-categories: urban sites, rural sites and remote sites.

Table 1 The information of monitoring sites of EANET China

City Name	Site classification	Site Name	Longitude	Latitude	altitude(m)
Chongqing	Rural site	Jinyunshan	106°22′	29°49′	800
	Urban site	Haifu	106°30′	29°37′	317
Xi'an	Urban site	Shizhan	108°57′	34°14′	400
	Remote site	Jiwozi	108°48′	33°50′	1800
Xiamen	Urban site	Hongwen	118°08′	24°28′	50
	Remote site	Xiaoping	118°02′	24°51′	686
Zhuhai	Urban site	Xiangzhou	113°34′	22°16′	40
		Zhuxiandong	113°31′	22°12′	45
		Haibin-Park	113°34'	22°16'	15
Wuzhishan	Remote site	Wuzhishan	109°30′	18°50'	958
Lijiang	Remote site	Lijiang	100°15′	27°14'	3410

1.2.1 Chongqing:

In 2001-2019, the sites of Haifu (urban site) and Jinyunshan (rural site) in Chongqing had carried out acid deposition monitoring. Guanyinqiao (urban site) stopped its monitoring in 2008, because its environmental monitoring building was relocated to Haifu (urban site), which began to carry out acid deposition monitoring in 2008. The basic information of these two sites is as follows:

Jinyunshan: The monitoring site is located in Beibei District of Chongqing, with a longitude of 106°22' E, latitude of 29°49' N, about 40 kilometers from downtown. Jinyunshan is the key nature reserve of Chongqing. It extends about 16 km from northwest to southeast along the western margin of paralleled ridge-valley of East Sichuan. The altitude is between 700 and 900 meters, with a maximum of 952 meters, low mountain landscape. The area is featured by temperature changes, abundant rainfall, high soil and air humidity, which is conducive to plant growth, and the main vegetation is mixed vegetation communities dominated by evergreen trees, structurally stable and relatively well-preserved. As a nature reserve, it has no industry, but a small number of farm homes, nursing homes, resorts, and microwave stations. In recent years, a number of new cement plants have been built in northern part, and the residential quarters in southern part also witnessed certain expansion, which may affect the air quality of Jinyunshan.

Haifu: Guanyinqiao site stopped its monitoring at the end of 2007 due to the relocation of the building of Chongqing Environmental Monitoring Center in 2007. To ensure the continuity of EANET's monitoring, a new precipitation monitoring site, Haifu monitoring site (Qingsong Road No. 1, Yubei District, Chongqing; 106°30' E by longitude, 29°37' N by latitude, 317 meters by altitude) was selected, and it was 6 kilometers north by west of the original Guanyinqiao site, and located on the roof of a five-floor building. There is no major source of pollution around, bordering Zhaomushan Botanical Garden in the north and 1 kilometer north of the inner ring highway around Chongqing. The precipitation monitoring at the site was officially started in January 2008.

1.2.2 Xi'an:

In 2001-2019, the sites of Shizhan (urban site) and Jiwozi (remote site) in Xi'an City had carried out acid deposition monitoring. Due to the changes in surrounding circumstances and major transportation routes, the previous Weishuiyuan (rural site) no longer met EANET's technical requirements for rural sites, and stopped monitoring in 2007. The basic information of these two sites is as follows:

Shizhan: The site is located in the southern suburbs of Xi'an, with a longitude of 108°57' E, latitude of 34°14', and altitude of 400 meters. It is mainly surrounded by residential areas, commercial areas and transportation routes.

Jiwozi: The site is located in the southern mountainous area of Chang'an County of Xi'an, about 60 kilometers from downtown, low in northeast and high in southwest. It has a longitude of 108°48' E, latitude of 33°50' N, and altitude of 800-2000 meters. It is in warm temperate zone, with an annual average temperature of 13.2℃, annual average rainfall of 687mm. The temperature is relatively lower, and the frost-free period is about 150 days. The area is rocky, dominated by shrubs with sparsely distributed tall trees. The soil is fertile, mainly in brown. It boasts a large number of artificial forests, mainly Pinus armandi, dahurian larch and Pinus tabuliformis.

1.2.3 Xiamen:

In 2001-2019, the sites of Hongwen (urban site) and Xiaoping (remote site) in Xiamen City had carried out acid deposition monitoring. The basic information of these two sites is as follows:

Hongwen: The site (longitude 118°8' E, latitude 24°28' N, altitude 50 meters) is located in the middle of Xiamen Island, under the jurisdiction of the New Town of Xiamen at first and now a part of downtown Xiamen. The island has Yunding Peak in the southern part, the highest peak of the island, with vegetation coverage rate of over 90%, and the reservoir in the north is largest reserve water for the island. Accompanied by the development of urban construction, a number of transport routes such as Lianqian Road pass along this site.
Xiaoping: The site is located in the heart of remote forest areas of Xiamen, far away from highways, railways, urban areas and human activities, with a longitude of 118°2' E, a latitude of 24°51' N, and a altitude of 686 meters.

1.2.4 Zhuhai:

In 2001-2019, the sites of Xiangzhou (urban site) and Zhuxiandong (urban site) in Zhuhai City had carried out acid deposition monitoring. However, Zhuxiandong stopped monitoring in 2013, because its conditions are not suitable for acid deposition monitoring.
Xiangzhou: The monitoring site (113°34' E, and 22°16' N) is on the roof of the building of Zhuhai Environmental Monitoring Center in downtown Zhuhai. The main area is the location of government offices and departments, without industrial pollution sources in surrounding. The main pollution comes from motor vehicles and household sources. The site adjoins transport corridor Northern Haibin Road, 40 meters above sea level. In 2012, dry deposition monitoring of Xiangzhou site was transferred to Haibin-Park site, because the atmospheric monitoring of Xiangzhou was cancelled.

Zhuxiandong: This site (113°31'E, 22°12'N) is located in Zhuxiandong scenic tourist area of Nanping Township, about 15 kilometers from the city. It borders Lizhi Mountain in the south and Nanwan Road in the north, 45 meters above sea level. As the reservoir dam was strengthened in 2012, it was not suitable for acid deposition monitoring during the construction period, and thus the monitoring was suspended.

1.2.5 Wuzhishan and Lijiang:

Wuzhishan：Wuzhishan is a city of Hainan Province, which located in the south of China. This site (109°30'E, 18°50'N) is an atmospheric background station and its altitude is 958 meters.

Lijiang: Lijiang is a city of Yunnan Province, which located in the southwest of China. The longitude and latitude of Lijiang site is 100°15' east longitude and 27°14' north latitude, and the altitude is 3410 meters.

These two sites are all remote sites, which officially joined the network in 2019. These two sites are very representative, both of them located in a region with low population density, superior natural ecological environment, and far away from urban and man-made pollution sources, which can truly reflect the regional ambient air quality and acid rain background. The projects carried out at these two sites are wet deposition and dry deposition.

Table 2 The information of the monitoring sites

City Name	Site classification	Site Name	Wet deposition	Dry deposition	Soil and vegetation	Inland water
Chongqing	Rural site	Jinyunshan	√	√	√	√
	Urban site	Haifu	√			
Xi'an	Urban site	Shizhan	√			
	Remote site	Jiwozi	√		√	√
Xiamen	Urban site	Hongwen	√	√		
	Remote site	Xiaoping	√		√	√
Zhuhai	Urban site	Xiangzhou	√	√		
		Zhuxiandong	√		√	√
		Haibin-park		√		
Wuzhishan	Remote site	Wuzhishan	√	√		
Lijiang	Remote site	Lijiang	√	√		

1.3 Monitoring plans in 2001-2019

CNEMC develops national monitoring plans each year, and the participating cities carry out monitoring work according to EANET's technical guidelines, and submit data to CNEMC as required.

1.3.1 Wet deposition monitoring

Wet deposition monitoring covers: rainfall, pH of rainfall, EC, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+} ions. The monitoring cycle is 24 hours, from 9:00 am to 9:00 am the next day.

1.3.2 Dry deposition monitoring

Each of the six cities of EANET China selects 1 site for dry deposition monitoring at a frequency of one hour, covering SO_2, NO_2 and PM_{10} in the air. Among them, Hongwen site of Xiamen City carried out four stage filter pack method sampling for dry deposition. The Network Center provided Xiamen Environmental Monitoring Center with four stage filter pack sampling devices in September 2006, which were installed and started to run by the end of 2006. The sampling period is once a week, with air flow rate of 1 l/min. The items include gaseous pollutants (SO_2, HCl, HNO_3 and NH_3) and chemical compositions in particulate matters (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^- and Cl^-). In 2012, the monitoring was stopped due to device failure which cannot be repaired in China.

1.3.3 Inland water monitoring

Inland water monitoring covers pH, EC, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} ions and alkalinity, and the monitoring frequency is once every 3 months, 4 times per year. Moreover, color, transparency, COD, NO_2^- and PO_4^{3-} are suggested to be monitored once a year.

1.3.4 Soil and vegetation monitoring

In 2001, the environmental monitoring center of Zhuhai and Xi'an carried out soil monitoring respectively. In 2003, according to the revised national monitoring plan, soil monitoring and vegetation survey shall be conducted once 3-5 years. Except two new cities, Wuzhishan and Lijiang, the other 4 participating cities of EANET China carried out soil and vegetation monitoring.

Soil monitoring covers: pH(H_2O), pH(KCl), exchangeable Na^+, K^+, Ca^{2+}, Mg^{2+}, ECEC (effective cation exchangeable capacity), exchangeable acidity, exchangeable Al^{3+}, exchangeable H^+, available phosphate(voluntary item), T-N(optional item), T-C(optional item), Sulfate(voluntary item).

Vegetation monitoring covers: description of trees, understory vegetation survey, observation of tree decline, etc.

Table 3 Monitoring Parameters and Frequency of EANET China

Content	Monitoring Parameters	Frequency
Wet deposition	pH, EC, rainfall, SO_4^{2-}, NO_3^- ,Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+},	24h, 09:00-09:00
Dry deposition	SO_2, NO_2, PM_{10}	1h
Inland water	pH, EC, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, alkalinity	4 times per year
	Water color, transparancy, COD, NO_2^-, PO_4^{3-}	Once a year
Soil	pH(H_2O), pH(KCl), exchangeable Na^+, K^+, Ca^{2+}, Mg^{2+}, ECEC(effective cation exchangeable capacity), exchangeable acidity, exchangeable Al^{3+}, exchangeable H^+, available phosphate(voluntary item), T-N(optional item), T-C(optional item), Sulfate(voluntary item)	Every 3-5 years
Vegetation	description of trees, understory vegetation survey	Every 3-5 years
	observation of tree decline	Every year

1.4 Sample Collection and Sample Analysis

1.4.1 Sample Collection and Preservation

Each monitoring site of EANET China uses auto samplers to collect rain samples. The samples are collected every 24 hours, from 9:00 am to 9:00 the next morning.

After collecting samples, the staff weigh the rainwater at the scene weight, and record it. After EC and pH measurement, the remaining samples are collected in special acid rain sampling bottles, stored in a refrigerator at 4℃ for ion analysis. The information of sampling devices used at each monitoring site of EANET China is shown in Table 4.

Table 4 Sampling method, instrument information of the monitoring sites (2019)

City name	Monitoring site	Sampling method	Sampler information
Chongqing	Jinyunshan	auto	ZJC-V (Hangzhou Hengda)
	Haifu	auto	US-320H (Ogasawara)
Xi'an	Shizhan	auto	DSSI (Xuanhui, Qingdao)
	Jiwozi	auto	XHARS30A (Hebei Sailhero)
Xiamen	Hongwen	auto	ZJC-II (Hengda,Hangzhou)
	Xiaoping	auto	ZJC-II (Hengda,Hangzhou)
Zhuhai	Xiangzhou	auto	US-320H (Ogasawara)
	Zhuxiandong	auto	ZJC-III (Hengda,Hangzhou)
Wuzhishan	Wuzhishan	auto	LAOYING 5020 (Laoying, Qingdao)
Lijiang	Lijiang	auto	ZJC-V (Hengda,Hangzhou)

1.4.2 Sample analysis

The relevant information of samples must be recorded in detail at sampling sites, and transferred to laboratory analysts. The samples are filtered with 0.45 micron membrane for ion analysis which should be completed within a week.

Table 5 Measurement method, instrument information of the laboratory

City name	Monitoring parameters	Measurement method	Instrument information
Chongqing	pH	Glass electrode method	METTLER TOLEDO 320
	EC	electrode method	TOA-DKK
	F^-, Cl^-, NO_3^-, SO_4^{2-}	IC	DIONEX ICS
	Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	IC	DX-500
Xi'an	pH	Glass electrode method	Rex Electric PHSJ-4A
	EC	electrode method	Rex Electric DDSJ-308A
	NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} Cl^-, NO_3^-, SO_4^{2-}	IC	DIONEX ICS-5000
Xiamen	pH	Glass electrode method	Mettler Toledo
	EC	electrode method	Mettler Toledo
	Cl^-, NO_3^-, SO_4^{2-}	IC	DX-320
	Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	IC	DX-320
Zhuhai	pH	Glass electrode method	ORION 420A
	EC	electrode method	Rex Electric
	NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} Cl^-, NO_3^-, SO_4^{2-}	IC	DIONEX-ICS-1000
Wuzhishan	pH	Glass electrode method	Mettler Toledo S210
	EC	electrode method	Mettler Toledo S230
	NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} Cl^-, NO_3^-, SO_4^{2-}	IC	DIONEX ICS-1100
Lijiang	pH	Glass electrode method	PHS-3E (Leici,Shanghai)
	EC	electrode method	DDS-307 (Shanghai)
	NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} Cl^-, NO_3^-, SO_4^{2-}	IC	DIONEX ICS-1100

1.4.3 QA/QC of wet deposition monitoring

According to EANET's requirements for QA and QC of wet deposition monitoring, all the six member units of EANET China adhere strictly to QA and QC requirements in all aspects of monitoring. The analysis laboratories of the four cities (Chongqing, Xi'an, Zhuhai, Xiamen) have participated into inter-laboratory comparison tests of EANET each year since 2001 (covering wet deposition, dry deposition, soil and inland water), and achieved satisfactory results.

The pass rates of ion equilibrium test parameters R_1 and EC test parameters R_2 in rainfall analysis

of the six cities of EANET China during the year of 2001-2019 are listed in Figure 1 and Figure 2. The pass rate of R_2 was always better than R1 during the 20 years. The pass rates of R_1 and R_2 remained stable between 2006 and 2019, and had higher correlation than the data at the beginning of participation into EANET (2001-2006), which implied the improvement of data quality.

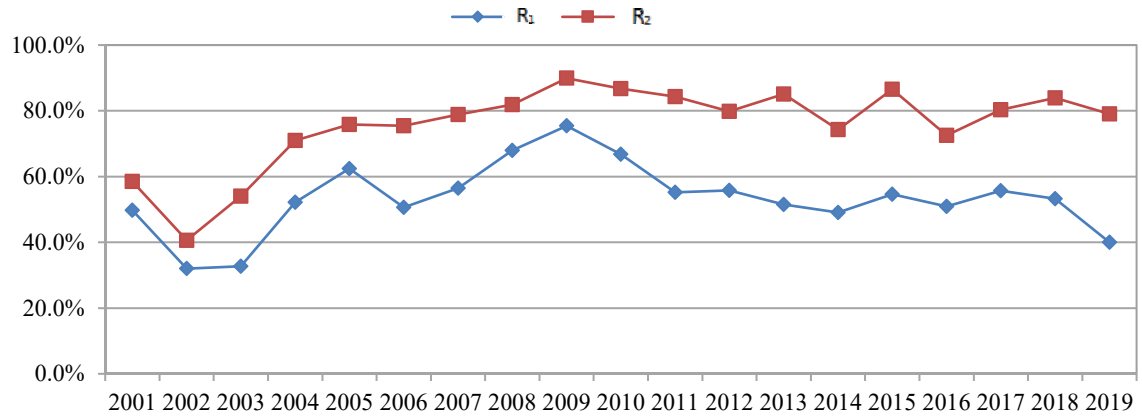


Figure 1. Comparison of R_1 and R_2, all sites of EANET China from 2001 to 2019.

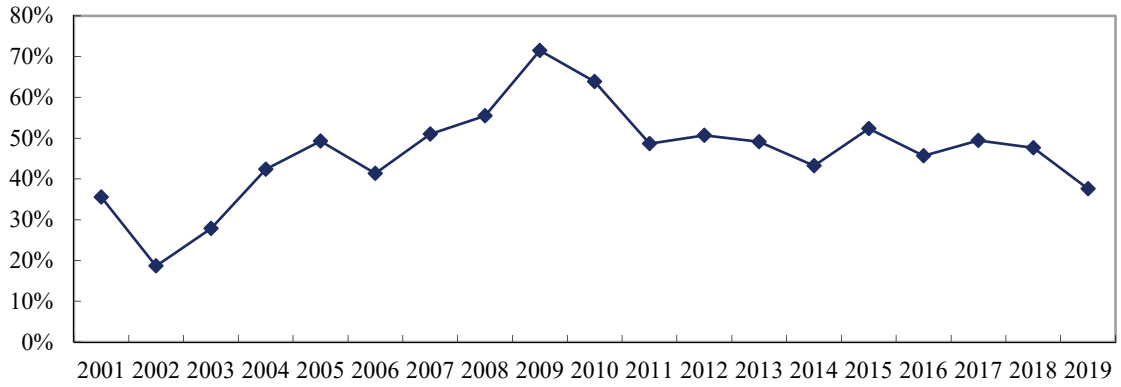


Figure 2. The average of Comparison both R_1 and R_2, EANET China from 2001 to 2019.

PH standard buffer solution should be used for calibration before testing the pH value of rainfall each time. Since the pH values of most rainfall samples range between 3.0 and 7.5, the standard buffer solution with a pH of 4.0-7.0 is generally used for calibration. Standard buffer solution should be preserved in 4℃ refrigerators, and changed regularly (usually every 1 months).

EC meter is calibrated with multi-point calibration method. Before measuring the EC of rainfall samples, deionized water is used to dilute 0.01mol/L KCl standard solution into 0.0001, 0.0005 and 0.001mol/L KCl solution to calibrate EC meter, and the EC of deionized water also needs to be measured. When conditions permit, the sample and standard solution should be measured at 25°C water bath conditions. Standard calibration solution should be changed regularly (once a month). In analyzing rainfall ion composition through ion chromatography, a calibration curve connecting at least 5 concentration points is drawn each time, and blank sample should be measured in each test, and more than 10% of actual number of samples are selected for parallel double measurement.

Chapter 2 Status Quo of Acid Deposition of EANET China

2.1 Atmospheric Deposition

2.1.1 Wet deposition of EANET China

2.1.1.1 EC and pH of wet deposition of EANET China in 2000-2019

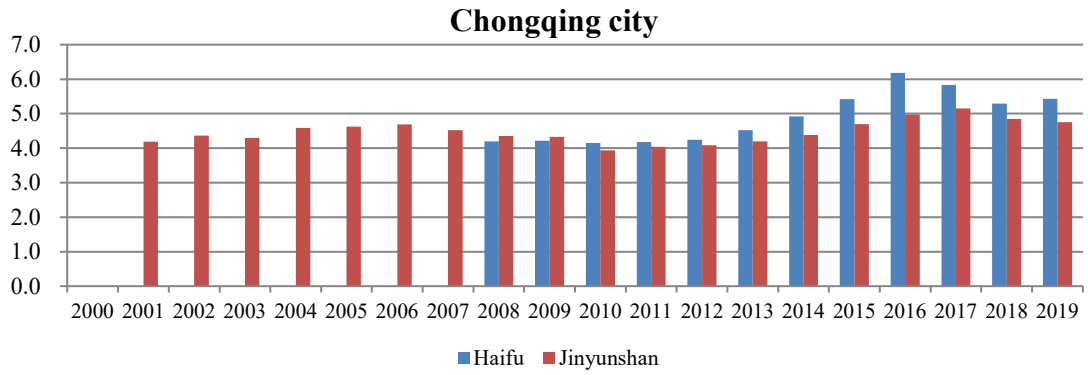


Figure 3. Annual average pH of Chongqing city, EANET China，2001-2019.

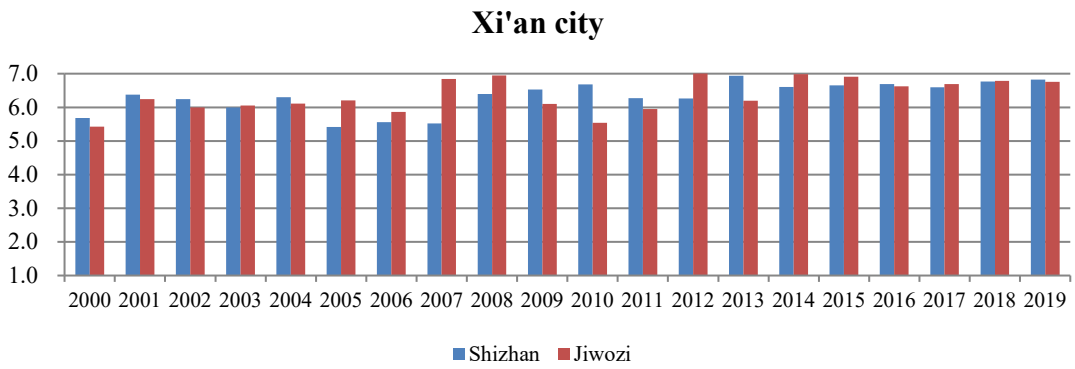


Figure 4. Annual average pH of Xi'an city, EANET China，2000-2019.

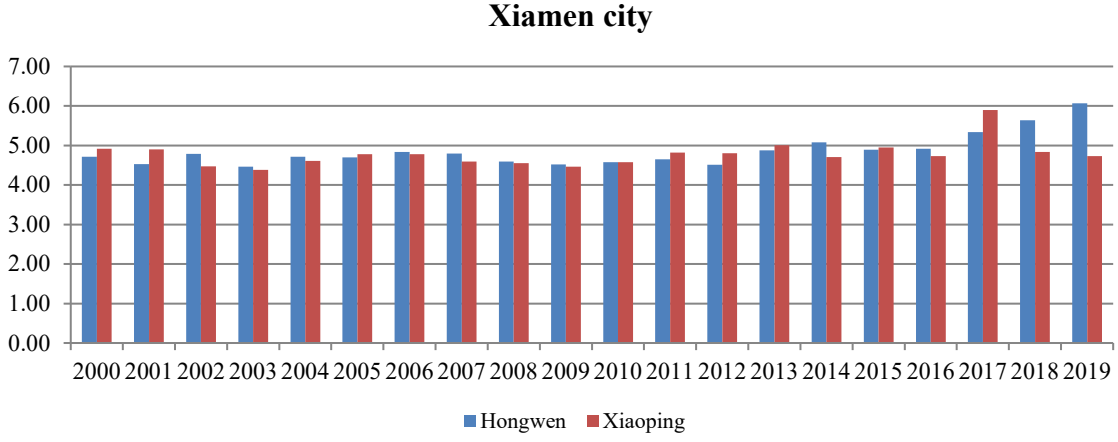


Figure 5. Annual average pH of Xiamen city, EANET China，2000-2019.

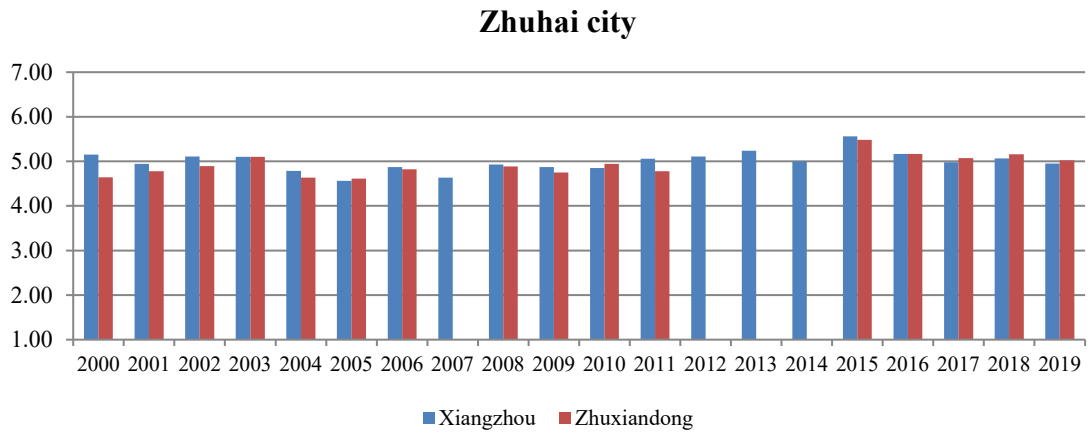


Figure 6. Annual average pH of Zhuhai city, EANET China，2000-2019.

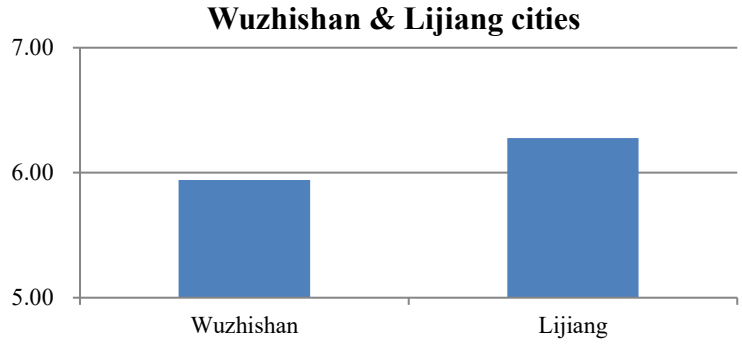


Figure 7. Annual average pH of Wuzhishan and Lijiang cities, EANET China in 2019.

The annual average pH values of all 10 acid deposition monitoring sites in 6 cities in 2000-2019 were shown in Figure 3 to Figure 7 (Wuzhishan and Lijiang cities only had the data in 2019). As shown in Figure 8, the annual average pH of EANET China in 2000-2019 ranged from 3.94 to 7.12, the lowest annual average pH 3.94 was observed at Jinyunshan site in 2010, and the highest pH 7.12 was observed at Jiwozi site in 2012.

According to the values of annual average, Xi'an in northwest of China had the highest annual average pH than the other cities in the EANET China. Chongqing in southwest of China had the lowest annual average pH before 2010, but after 2010 the annual average pH of Chongqing had an obvious growth. Xiamen and Zhuhai both in southeast coastal of China areas were close to each other in this regard. The annual average pH of Wuzhishan and Lijiang, which joined in the EANET in 2019, were in the middle level of all EANET cities of China. In most of years, the annual average pH values of rural sites and remote sites of all cities were lower than those of urban sites.

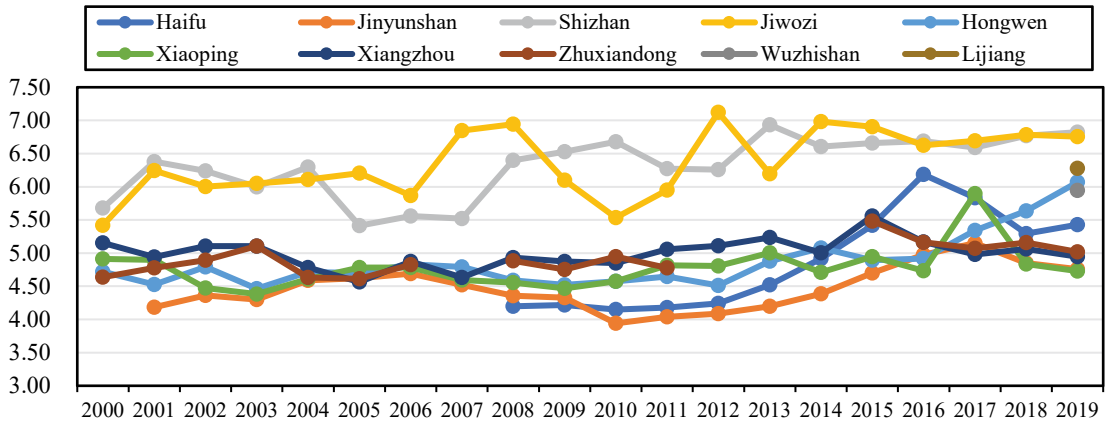


Figure 8. Trends of annual average pH of all monitoring sites, EANET China in 2000-2019.

From the long-term perspective from 2000 to 2019, the change in annual average pH of EANET China had slightly upward trends (Figure 8), especially from 2010 to 2019, it showed a more obvious upward trend.

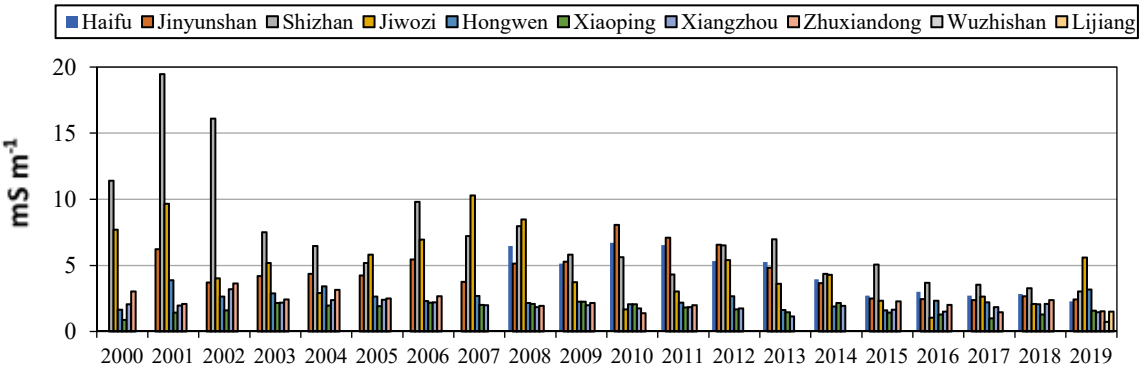


Figure 9. Annual average EC of all monitoring sites of EANET China, 2000-2019.

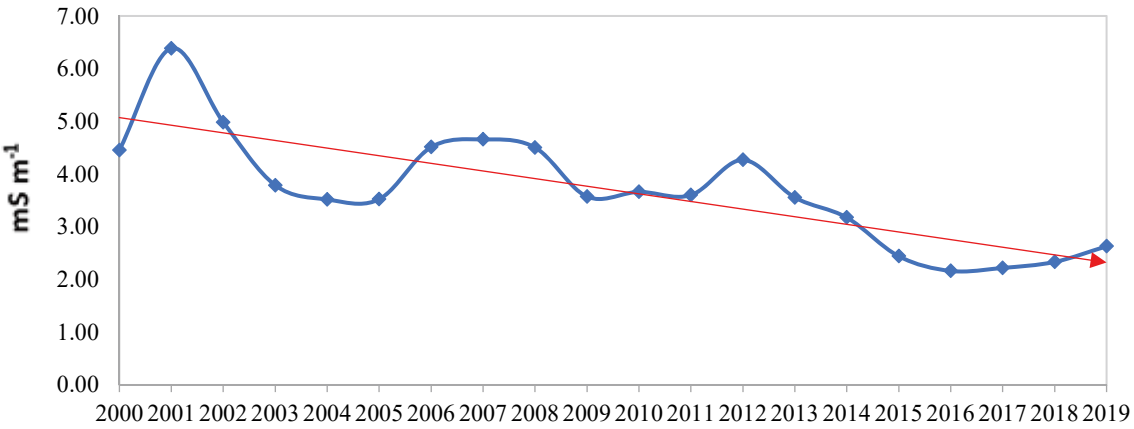


Figure 10. Trends of annual average EC of overall EANET China in 2000-2019.

The annual average EC of all monitoring sites in EANET China in 2000-2019 were shown in Figure 9. It can be found that the annual average EC values of Chongqing and Xi'an were higher than those of Xiamen, Zhuhai, Wuzhishan and Lijiang cities. This appearance was expressed very clearly from 2000 to 2014, but the annual average EC values of Chongqing and Xi'an were decreased obviously, and after 2014 the values were more and more close to the other cities that had lower values in EANET China.

From the long-term perspective from 2000-2019 (shown in Figure 10), the change in annual average EC of EANET China presented a clearly downward trend.

2.1.1.2 Concentrations of major ions of wet deposition of EANET China in 2000-2019

The annual average SO_4^{2-}, NO_3^- and Cl^- ions concentrations of wet deposition monitoring sites in 2000-2019 were shown in Figure 11-13. Generally, Xi'an in the northwest and Chongqing in the southwest of China had significantly higher SO_4^{2-} and NO_3^- ion concentrations than Xiamen and Zhuhai that in the southern coastal areas of China, but regarding Cl^- ion concentration, the former was lower than the latter in most of years, and this may be due to the wet deposition of the latter, which were affected by sea salt particles. Moreover, of all monitoring sites, SO_4^{2-}, NO_3^- and Cl^- ion concentrations of rural and remote sites were relatively lower than those of urban sites.

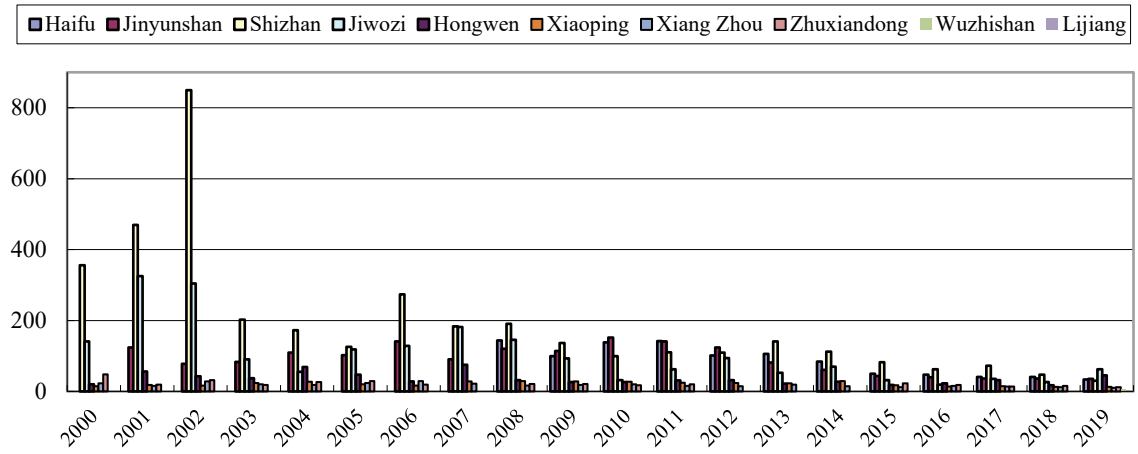


Figure 11. Annual average of SO_4^{2-} concentration of all monitoring sites, EANET China, 2000-2019 (unit: μmol L^{-1}).

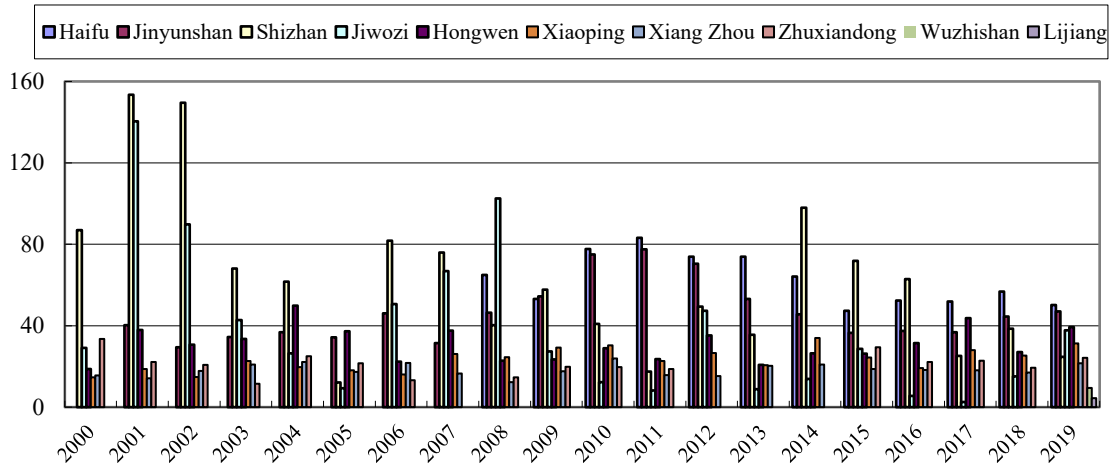


Figure 12. Annual average of NO_3^- concentration of all monitoring sites, EANET China, 2000-2019 (unit: μmol L^{-1}).

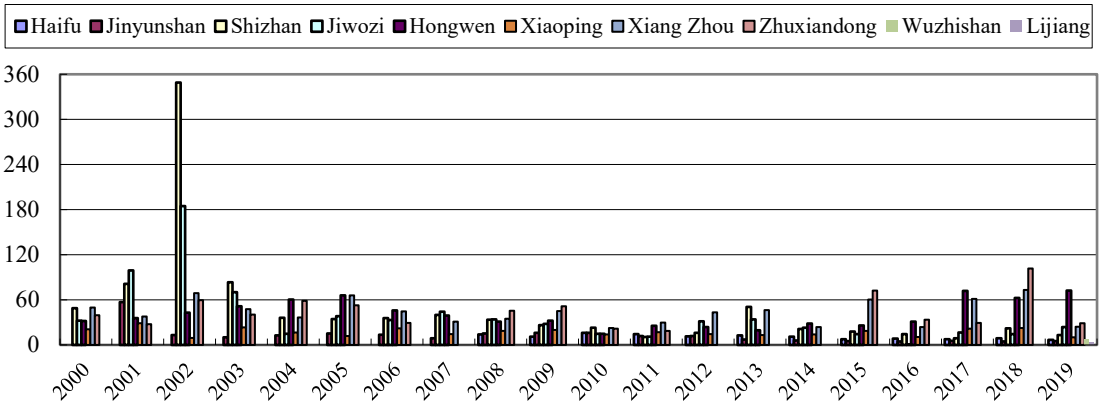


Figure 13. Annual average of Cl^- concentration of all monitoring sites, EANET China, 2000-2019 (unit: μmol L^{-1}).

SO_4^{2-} and NO_3^- ions were the major acidic ions in wet deposition, and the annual concentrations of these two major acidic ions of the 4 cities (except Wuzhishan and Lijiang cities) in 2000-2019 were shown in Figure 14. From the long-term perspective in these 20 years, the SO_4^{2-} concentration of EANET China exhibited an obvious decline trend. The annual average NO_3^- concentration of EANET China in these 20 years also had a slightly decline trend, but the decline range was much smaller than SO_4^{2-}.

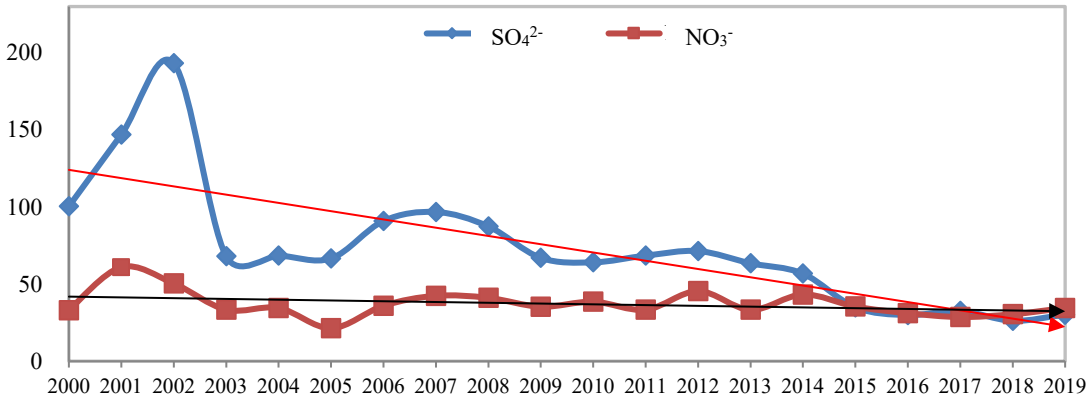


Figure 14. Trends of annual average of SO_4^{2-} and NO_3^- concentration overall EANET China, in 2000-2019 (unit: μmol L^{-1}).

From the Figure 14, another important phenomenon was found. The SO_4^{2-} concentration in the wet deposition of EANET China before the year of 2015 usually was higher than the NO_3^- concentration. During the 20 years, the SO_4^{2-} concentration had greatly decreased and was getting close to the NO_3^- concentration. After 2015, these two ion concentrations data became very close, and the NO_3^- concentration is even higher than that of SO_4^{2-} in recent years. It implies that the emission of SO_4^{2-} precursors in the atmosphere decreased obviously during the 20 years, especially after the year of 2015.

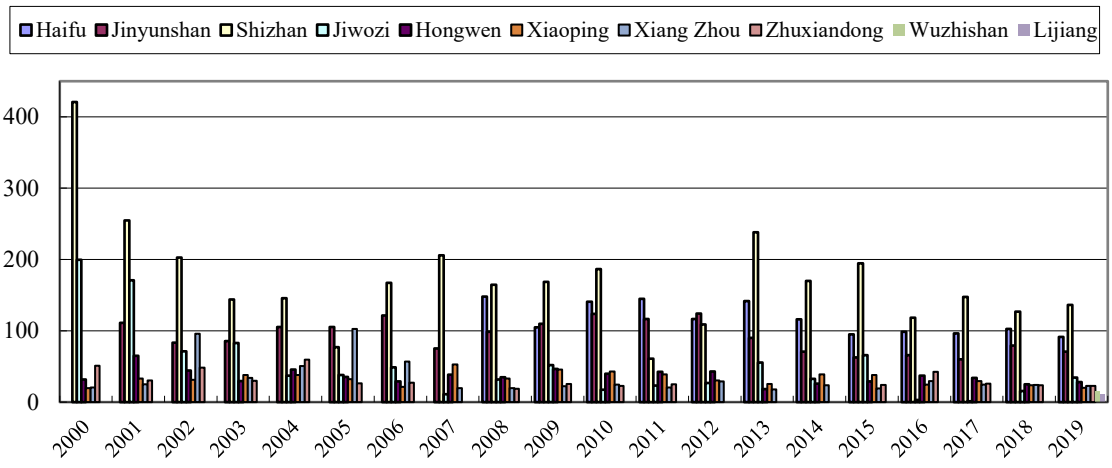


Figure 15. Annual average NH_4^+ concentration of all monitoring sites, EANET China, 2000-2019 (unit: μmol L^{-1}).

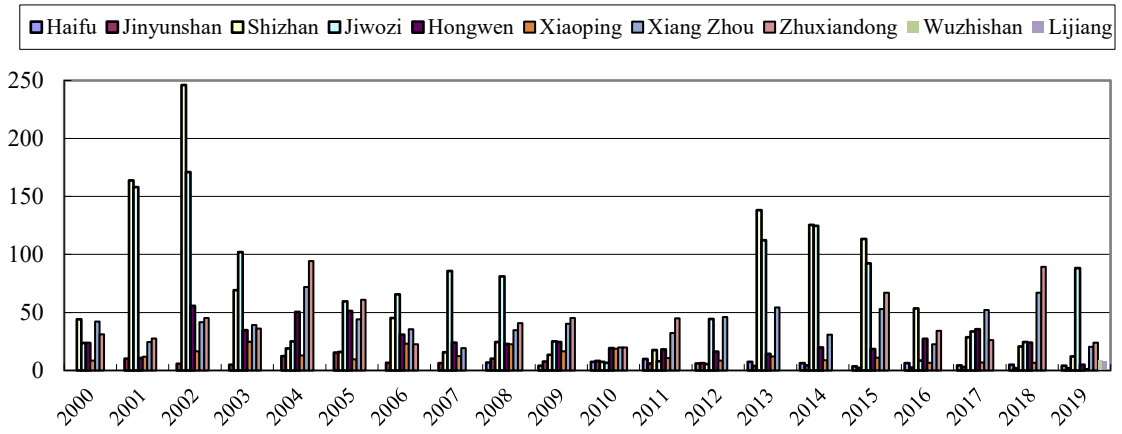


Figure 16. Annual average Na^+ concentration of all monitoring sites in EANET China, 2000-2019 (unit: µmol L^{-1}).

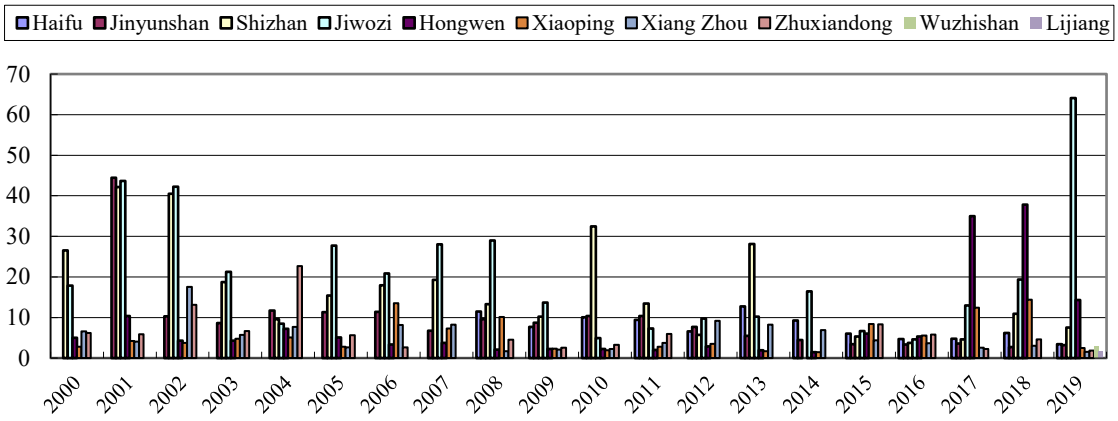


Figure 17. Annual average K^+ concentration of all monitoring sites, EANET China, 2000-2019 (unit: µmol L^{-1}).

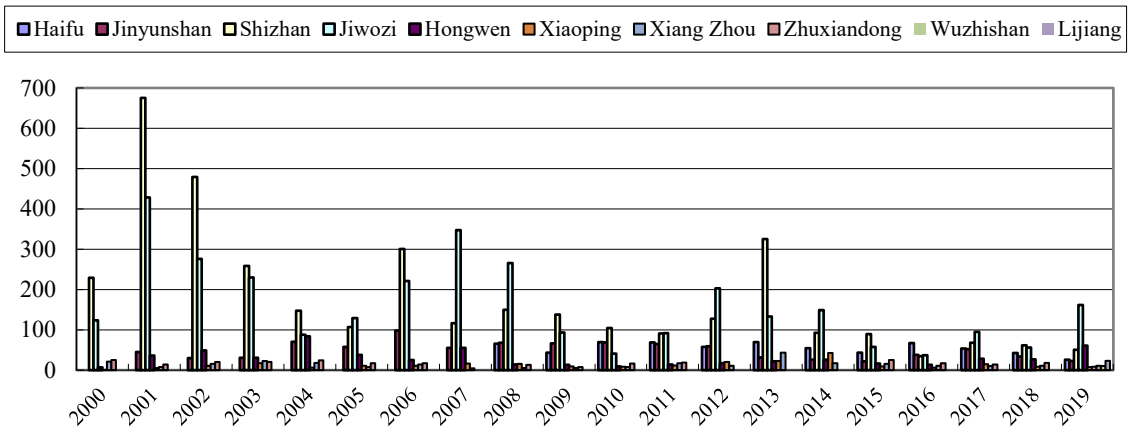


Figure 18. Annual average Ca^{2+} concentration of all monitoring sites, EANET China, 2000-2019 (unit: µmol L^{-1}).

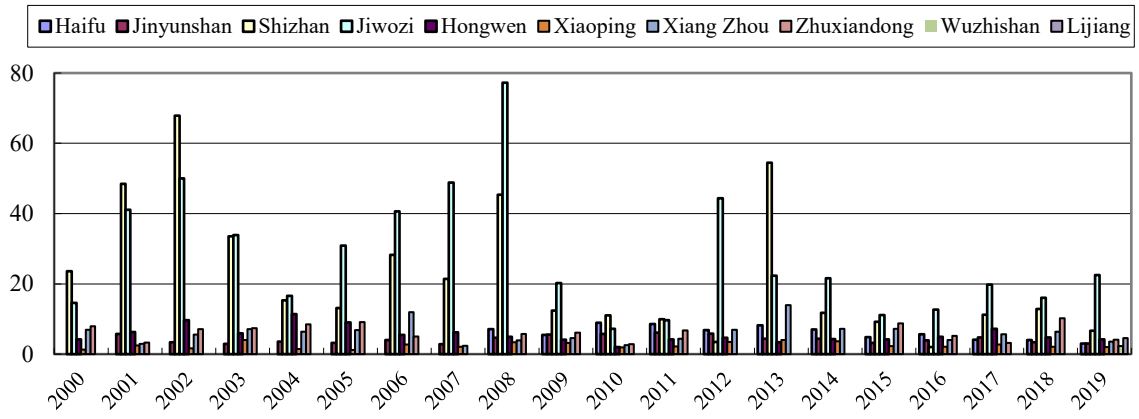


Figure 19. Annual average Mg^{2+} concentration of all monitoring sites, EANET China, 2000-2019 (unit: μmol L^{-1}).

The annual average concentrations of NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+} in wet deposition during 2000-2019 were shown in Figure 15-19. Geographically, the annual average of cation ions in wet deposition of rural and remote sites were relatively lower than those of urban sites. And in most of the years, the annual average of cation ions values of Xi'an and Chongqing were higher than the other cities in EANET China. From a long-term perspective, some of the annual data of these cation ions, like Ca^{2+} and Mg^{2+} ions, also had a slightly decline trend, but it was not obvious, however there were no significant trend changes in the other cation ions.

2.1.2 Dry deposition of EANET China

The sites of Jinyunshan in Chongqing, Hongwen in Xiamen and Xiangzhou in Zhuhai had started dry deposition monitoring since 2001. Weishuiyuan site carried out dry deposition monitoring from 2001 to 2006, but stopped later, because its surrounding environment no longer met the requirements for rural sites. Therefore, EANET China had Jinyunshan, Hongwen and Xiangzhou（Haibin-park after 2012）sites for dry deposition monitoring during 2000-2019, and Wuzhishan and Lijiang sites since 2019, covering SO_2, NO_2 (or NO, NO_X) and PM_{10}, and they all adopted automatic air monitoring at a frequency of 1 hour.

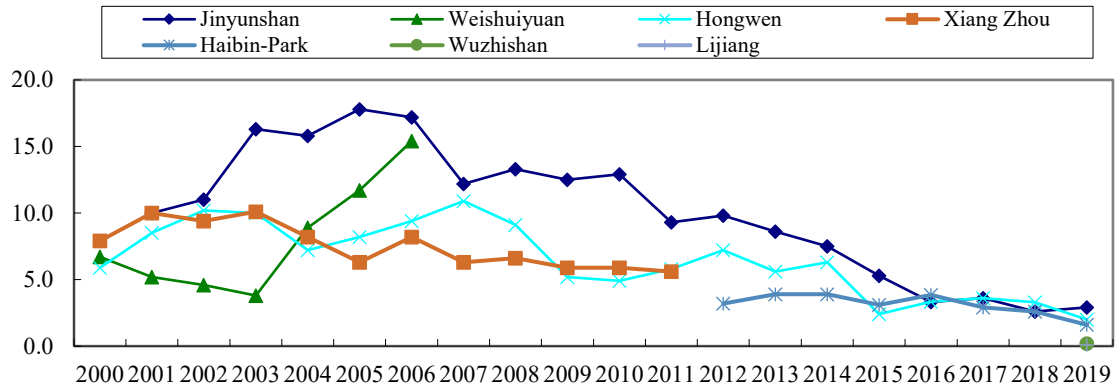


Figure 20. Trends of annual average of SO_2 concentration of EANET China, 2000-2019 (Unit: ppb).

Figure 20 showed the annual average concentration of SO_2 at seven dry deposition monitoring sites during 2000-2019. It could be seen that Jinyunshan had a relatively higher annual average than other sites with increasing trends before 2008. Comparatively, the SO_2 concentration of all sites, especially Jinyunshan and Hongwen, had decreased significantly around 4 ppb in 2010-2019.

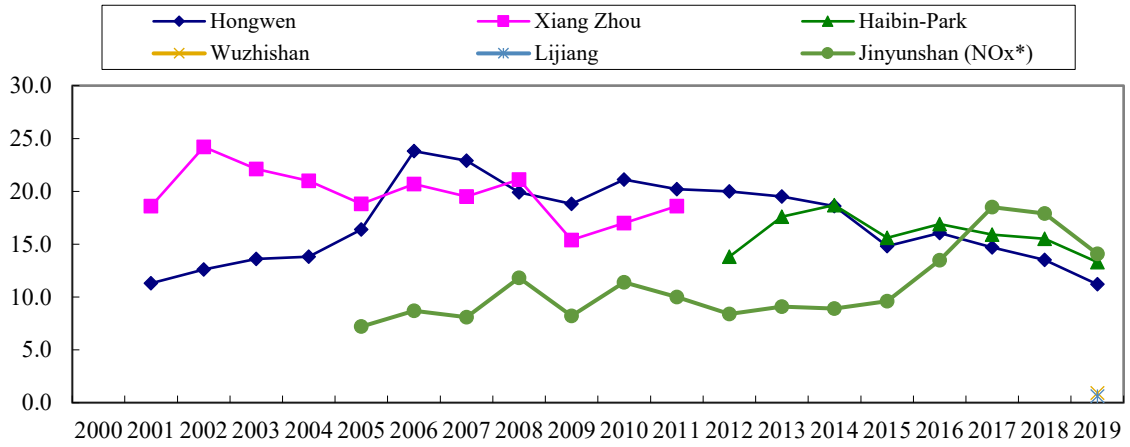


Figure 21. Trends of annual average of NO_2 and NO_X concentration of EANET China, 2001-2019 (unit: ppb).

Figure 21 showed the annual average concentration of NO_2 or NO_X at six dry deposition monitoring sites during 2000-2019. The results indicated that the NO_2 concentration of Hongwen, Xiang Zhou and Haibin-Park had downward trends in 2000-2019, but the data collected from Jinyunshan illustrated the growth of NOx during 2015-2019 than the past ten years.

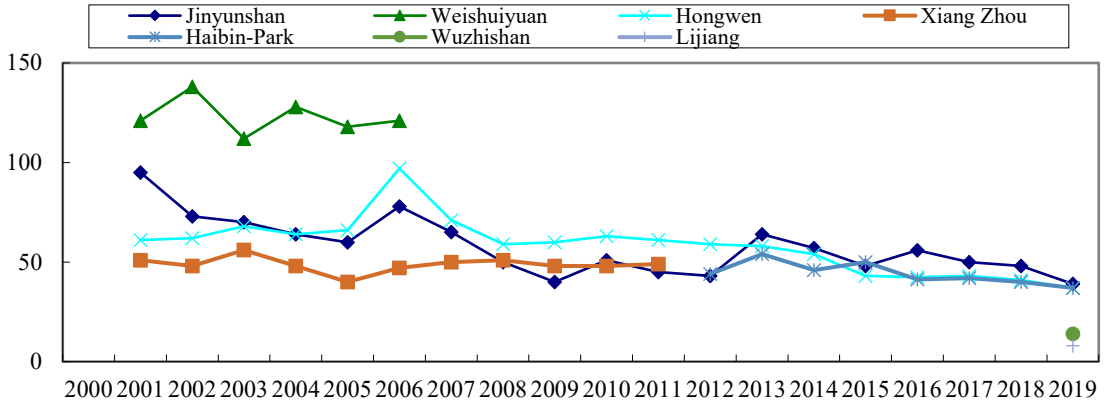


Figure 22. Trends of annual average of PM_{10} concentration of EANET China, 2001-2019 (unit: ppb).

The annual average concentrations of PM_{10} at seven dry deposition monitoring sites in 2001-2019 were presented in Figure 22. Despite of Weishuiyuan site, which highly varied from other sites and was stopped monitoring in 2006, Hongwen, Xiang Zhou and Haibin-park had similar trends, which had slightly downward trend since 2007. After the year of 2013, there was an obvious downward trend in the sites of Jinyunshan, Hongwen and Haibin-Park.

2.2 Inland water

Jinyunshan, Jiwozi, Xiaoping and Zhuxiandong, these 4 monitoring sites in 4 cities began inland water monitoring since 2001, and still kept the monitoring during 2001-2019, covering monitoring factors of two different monitoring frequencies. pH, EC, alkalinity, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+} were sampled and analyzed on a quarterly basis, while color, transparency, COD, NO_2^- and PO_4^{3-} were sampled and analyzed once a year.

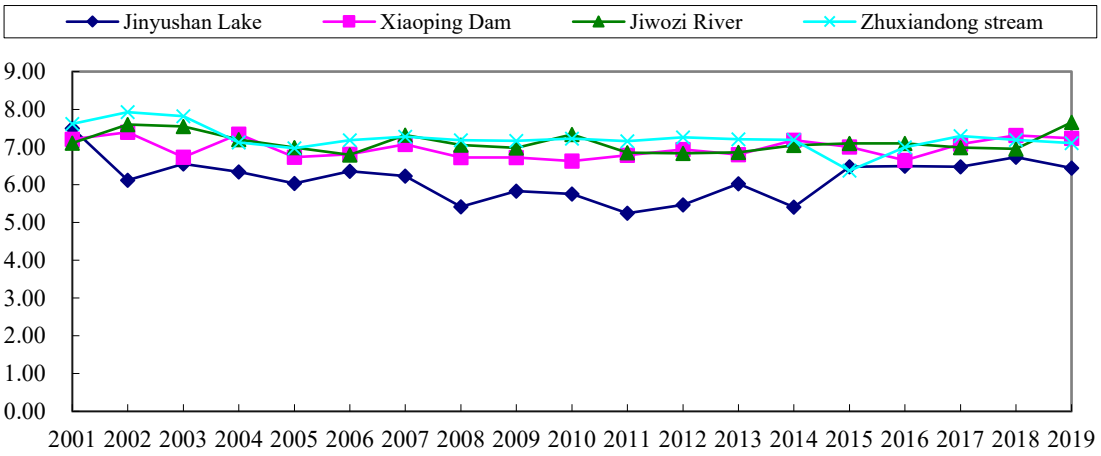


Figure 23. Trends of annual average of pH at the inland aquatic environment monitoring sites.

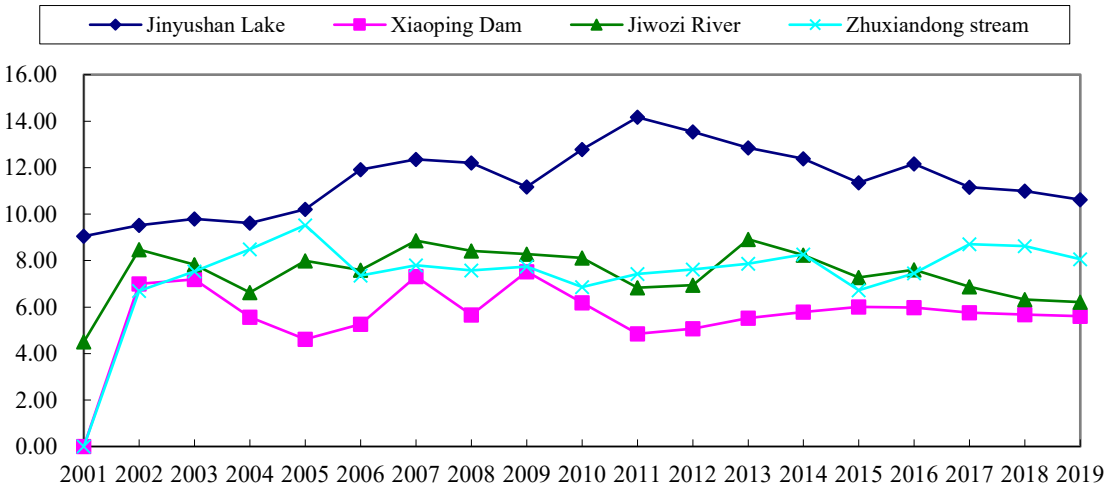


Figure 24. Trends of annual average of EC at the inland aquatic environment monitoring sites (unit: mS/m).

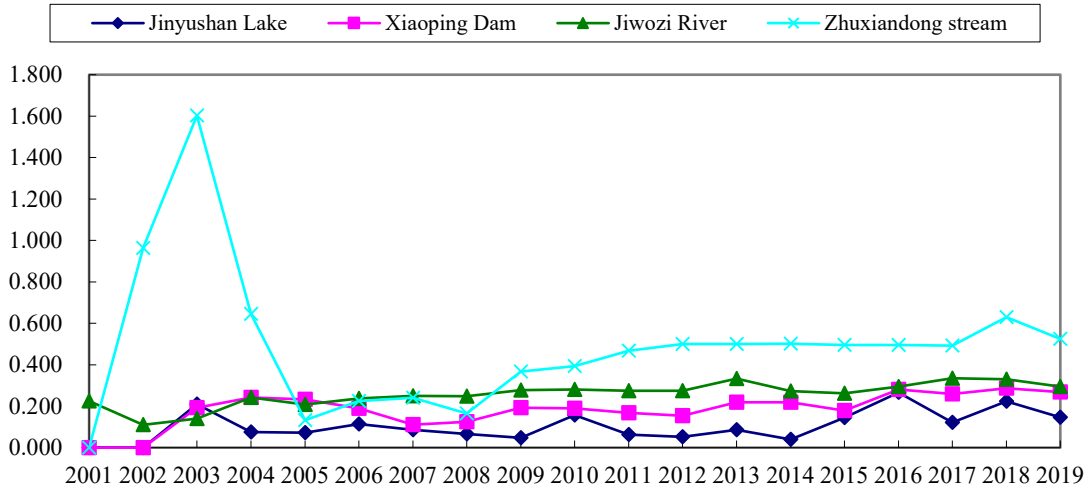


Figure 25. Trends of annual average of alkalinity at the inland aquatic environment monitoring sites (unit: meq/L).

The annual average pH, EC and alkalinity values of EANET China's four inland water monitoring sites in 2001-2019 were shown in Figure 23-25. Inland water at Jinyunshan site had relatively low annual average pH and alkalinity, with a high annual average EC at the same time. The annual average pH values of the other three sites were quite close. The annual average pH values of the four sites exhibited no prominent inter-annual variety during 20 years. The annual average EC values of the four sites also showed no prominent inter-annual variety. The annual average alkalinity values at Jinyunshan, Jiwozi, and Xiaoping sites were relatively stable during 2001-2019, while it had significantly higher values at the Zhuxiandong site during 2002-2004, it might be due to monitoring site which was not suitable for the requirement of EANET.

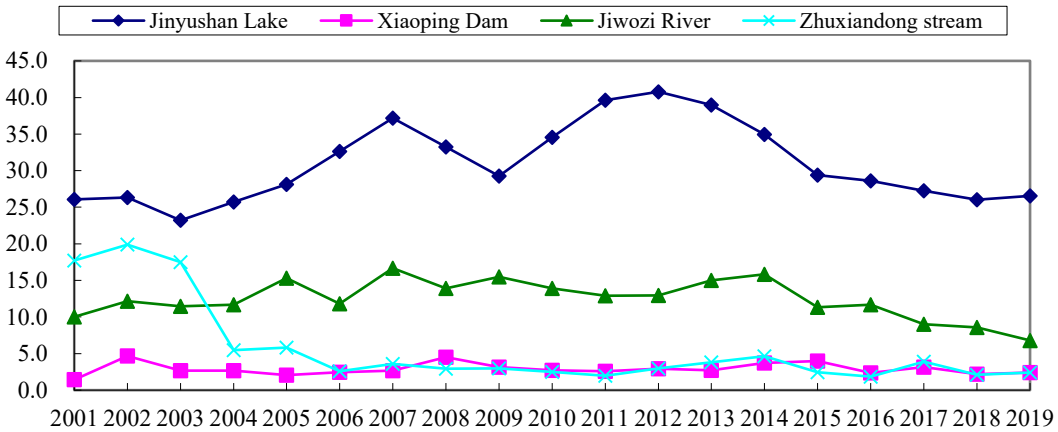


Figure 26. Trends of annual average of SO_4^{2-} at the inland aquatic environment monitoring sites (unit: mg/L).

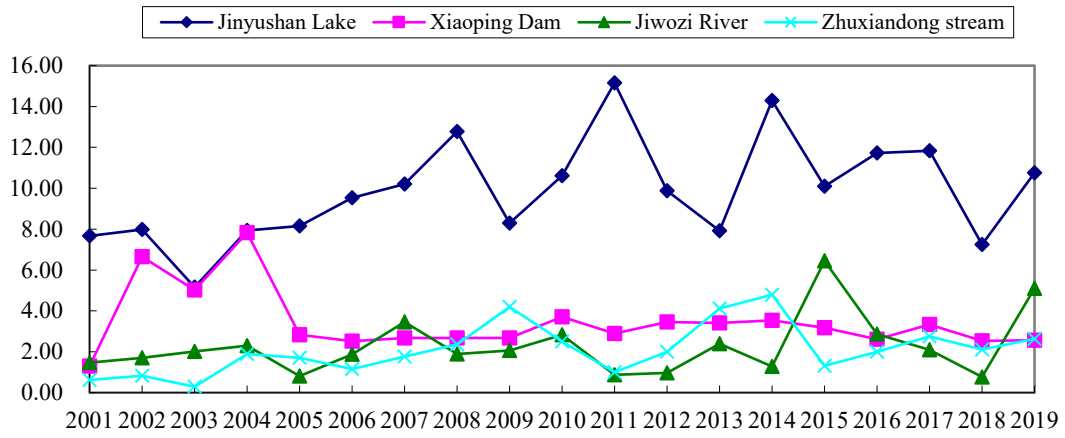


Figure 27. Trends of annual average of NO_3^- at the inland aquatic environment monitoring sites (unit: mg/L).

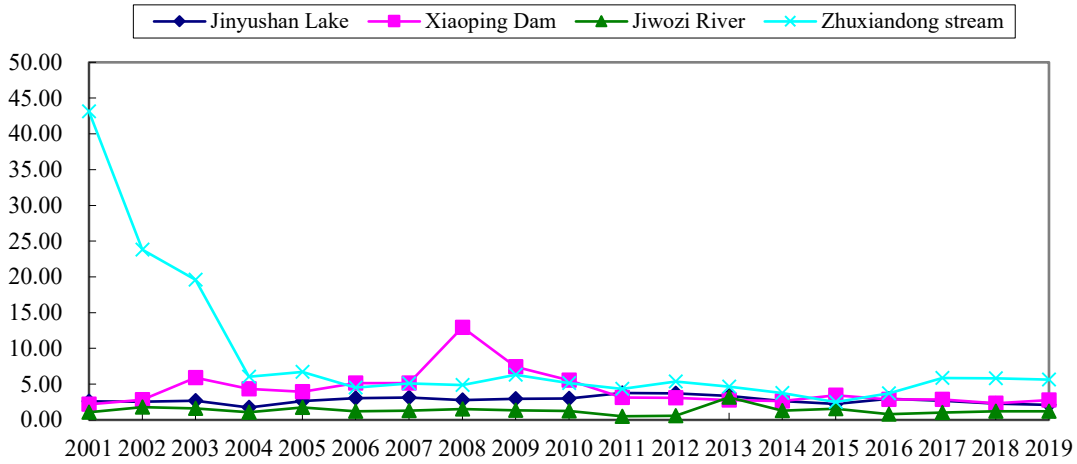


Figure 28. Trends of annual average of Cl^- at the inland aquatic environment monitoring sites (unit: mg/L).

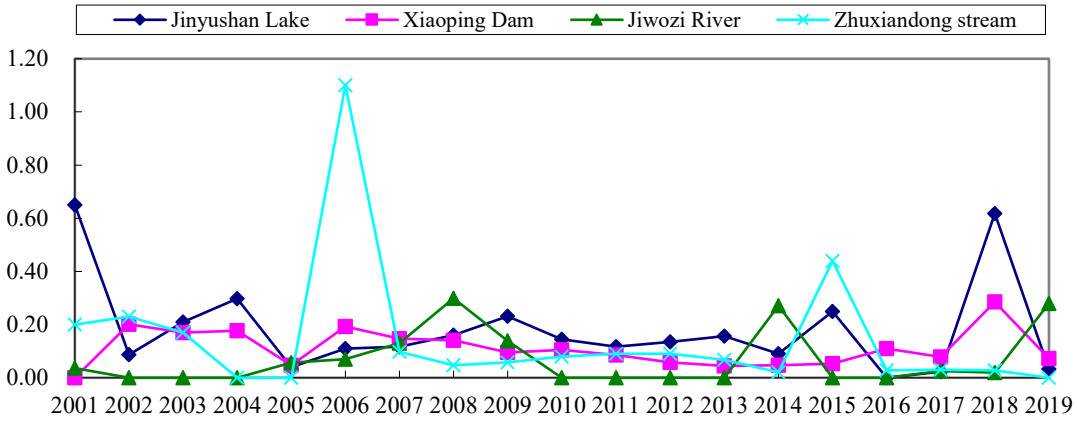


Figure 29. Trends of annual average of NH_4^+ at the inland aquatic environment monitoring sites (unit: mg/L).

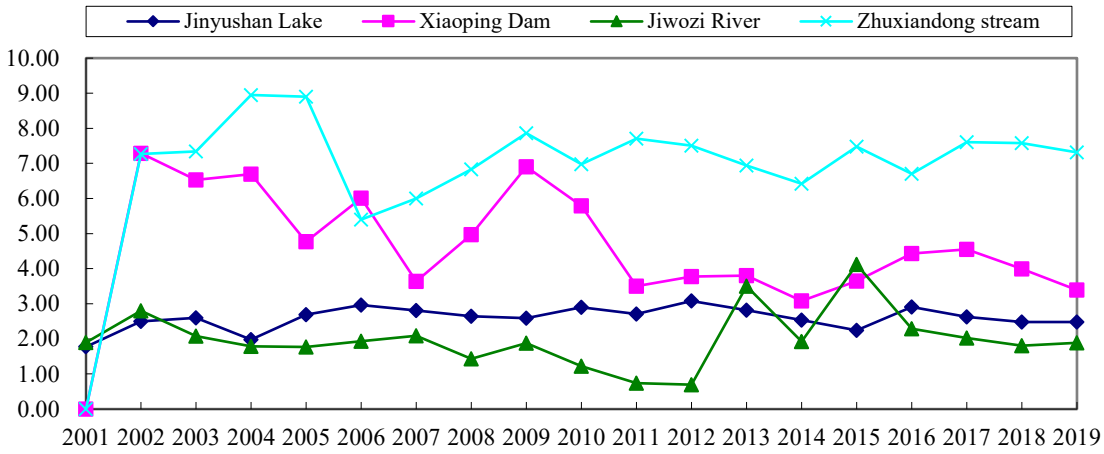


Figure 30. Trends of annual average of Na^+ at the inland aquatic environment monitoring sites (unit: mg/L).

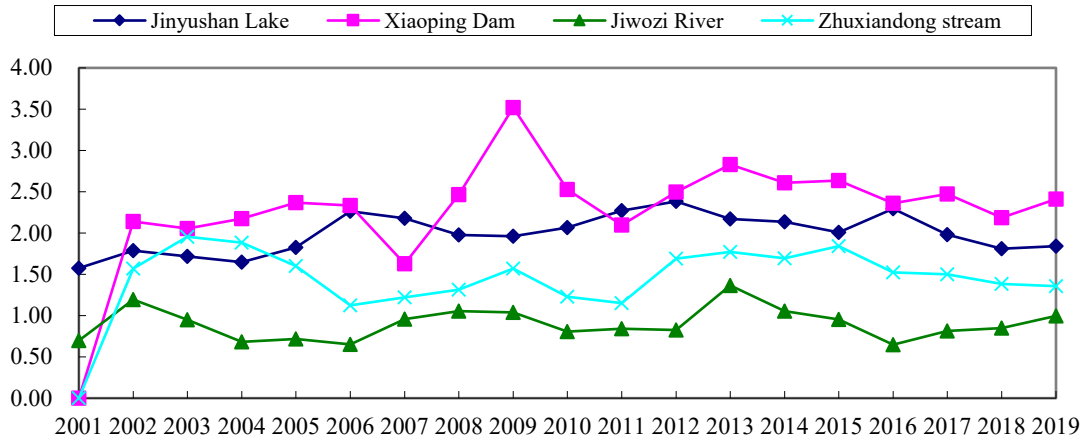


Figure 31. Trends of annual average of K^+ at the inland aquatic environment monitoring sites (unit: mg/L).

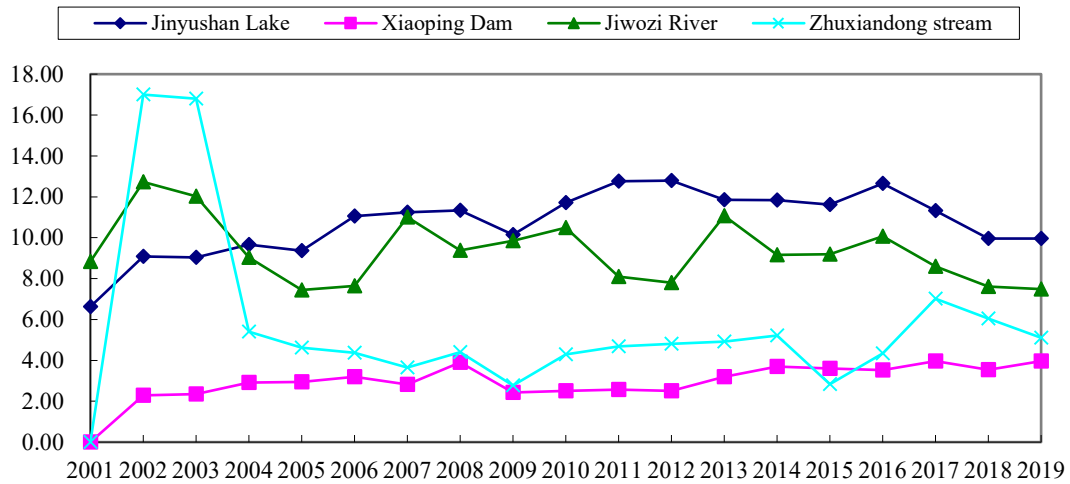


Figure 32. Trends of annual average of Ca^{2+}at the inland aquatic environment monitoring sites (unit: mg/L).

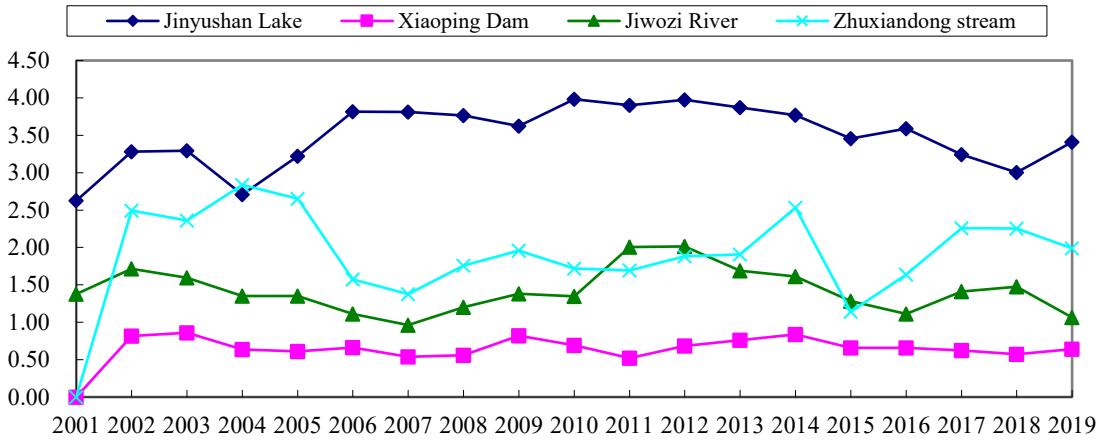


Figure 33. Trends of annual average of Mg^{2+} at the inland aquatic environment monitoring sites (unit: mg/L).

The trends of annual average concentrations of acidic ions SO_4^{2-}, NO_3^- and Cl^- at EANET China's four inland water monitoring sites in 2001-2019 were shown in Figure 26-28. Meanwhile, the trends of annual average concentrations of alkaline ions NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+} in 2001-2019 were shown in Figure 29-33.

The inland water monitoring sites in Chongqing and Xi'an these inland cities had significantly higher ion concentrations of SO_4^{2-} and Ca^{2+}, but lower ion concentrations of Cl^- and Na^+ than those in the coastal cities, including Xiamen and Zhuhai. The annual average concentrations of SO_4^{2-}, NO_3^-, Ca^{2+} and Mg^{2+} at Jinyunshan site in Chongqing were the highest in the four inland water monitoring cities. The Jiwozi site in Xi'an had the lowest annual average concentrations of Cl^-, Na^+ and K^+ for the four sites. The Xiaoping site in Xiamen had the highest annual average concentration of K^+, and the lowest annual average concentrations of Ca^{2+} and Mg^{2+} for the four sites. The Zhuxiandong site in Zhuhai had relatively higher concentration of Mg^{2+} and lower concentration of NO_3^- in the four sites. All these four sites had a low concentration of NH_4^+.

2.3 Overall analysis

From the long-term perspective about 20 years from 2000 to 2019, the change in annual average pH of EANET China had slightly upward trends, and the annual average pH values of rural sites and remote sites of all cities were lower than those of urban sites. The change in annual average EC of EANET China presented a clearly downward trend.

From the long-term perspective in these 20 years, the SO_4^{2-} concentration of EANET China exhibited an obvious decline trend. The annual average NO_3^- concentration of EANET China in these 20 years also had a slightly decline trend, but the decline range was much smaller than SO_4^{2-}. The SO_4^{2-} concentration had greatly decreased and was getting close to the NO_3^- concentration. After 2015, these two ion concentrations became much closer, and the NO_3^- concentration is even higher than the SO_4^{2-} concentration in recent years. It implies that the emission of SO_4^{2-} precursors in the atmosphere decreased.

In terms of dry deposition, the SO_2 concentration of all sites, especially Jinyunshan and Hongwen, had decreased significantly around 4 ppb in 2010-2019. The NO_2 concentration of Hongwen, Xiang Zhou and Haibin-Park had a downward trend in 2000-2019, but the data collected from Jinyunshan illustrated the growth of NOx during 2015-2019 than the past ten years. As for the PM_{10} data, there was an obvious downward trend of in the sites of Jinyunshan, Hongwen and Haibin-Park after the year of 2013.

As for inland water monitoring, the pH, EC and alkalinity of four cities showed a relatively stable values during 2000-2019, except the alkalinity of Zhuhai in 2002-2004. The inland cities, Chongqing and Xi'an, had significantly higher ion concentrations of SO_4^{2-} and Ca^{2+}, but lower ion concentrations of Cl^- and Na^+ than the data in the coastal cities, including Xiamen and Zhuhai. The annual average concentrations of SO_4^{2-}, NO_3^-, Ca^{2+} and Mg^{2+} at Jinyunshan site in Chongqing were the highest in the four inland water monitoring cities. All these four sites had a low concentration of NH_4^+.

Chapter 3 Review of China's Acid Deposition Policies

During 2001-2019, China had strengthened the rule of law, which mainly included improving the legal framework for air pollution control, strengthened law enforcement and combined administrative and judicial enforcements.

1. Implementing "National 12th Five-Year Plan for Environmental Protection"

The State Council adopted "National 12th Five-Year Plan for Environmental Protection" in 2011. In the planning, it was required to further double the efforts in sulfur dioxide and nitrogen oxides emission reduction, and cut sulfur dioxide emissions and nitrogen oxide emissions in 2015 by 8% and 10% respectively compared with 2010.

2. Revising "Ambient Air Quality Standards"

The Ministry of Environmental Protection issued the revised "Ambient Air Quality Standards" (GB 3095-2012) in February 2012, and determined the phase-based implementation plan. In 2012, the revised "Ambient Air Quality Standards" was scheduled to be implemented in Beijing-Tianjin-Hebei, the Yangtze River Delta, Pearl River Delta as well as municipalities and provincial capital cities in 2012, and expanded to 113 key environmental protection cities and national environmental protection model cities in 2013, all prefecture-level cities would implement new air quality standards in 2015, and it was scheduled to be adopted nationally after January 1, 2016.

Compared with the pre-revised version, the new standard adds annual and 24-hour average concentration limits of $PM_{2.5}$ and 8-hour average concentration limits of ozone (O_3), and tightens PM_{10} and NO_2 concentration limits.

3. Implementing "Air Pollution Prevention and Control Action Plan"

The State Council issued the "Air Pollution Prevention and Control Action Plan" in September 2013. It proposed that "After five years' efforts, the overall national air quality should be improved. Heavily polluted days should be reduced dramatically. Regional air quality in Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta would be turned better. Through another five years' or even longer efforts, heavily polluted days should gradually be eliminated and the national air quality should be improved significantly."

4. Formulating and revising laws and regulations

Since 2015, China has formulated and revised many laws and regulations on prevention and control of air pollution, including the Environmental Protection Law of the People's Republic of China, the Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution, the Law of the People's Republic of China on Environmental Impact Assessment, the Environmental Protection Tax Law of the People's Republic of China, the Law of the People's Republic of China

on Desert Prevention and Transformation, etc. In addition, local governments of the 31 provinces, municipalities and autonomous regions on the Chinese mainland promulgated or revised supporting regulations on environmental protection and prevention of air pollution. Some regions have even framed special legislation for key tasks.

In 2017, the targets of the Action Plan for the Prevention and Control of Air Pollution had been fully realized. In May 2018, the milestone National Conference of Ecological Environment Protection was held in Beijing. It upheld Xi Jinping thought on ecological civilization, and put forward a series of new ideas and strategies, highlighting those lucid waters and lush mountains are invaluable assets, and a good ecological environment was a boon for the people. The goal was to eliminate severe pollution and gave blue skies back to people. Guidelines on enhancing overall environment protection were issued after the conference, as well as a roadmap, mission statement and timetable for fighting the war against air pollution.

On June 27 in 2018, the State Council released the Three-Year Action Plan to Beat Air Pollution. It demanded to boost people's well-being through three years of effort, including significant reductions in total emissions of major air pollutants, decrease of $PM_{2.5}$ concentration and fewer days of severe pollution in a year.

5. Science and Technology Support and Management Innovation

China had been improving Air Quality Monitoring Network since 2013, and it had been expanding rapidly. China's ambient air quality monitoring system had four levels, including state, provincial, city and district（county）, with more than 5,000 monitoring sites. In November of 2016, China started building a national atmospheric particulate composition monitoring network, and in 2018, started building a national atmospheric photo chemistry monitoring network.

In an effort to urge local governments to take primary responsibility, a central supervision campaign for environmental protection was launched in December 2015, and it took three years to carry out inspections in 31 provinces, municipalities and autonomous regions across the nation. China had established coordinated air pollution prevention and control mechanisms in key areas including the Beijing-Tianjin-Hebei region and nearby regions, the Yangtze River Delta and the Fenwei Plain. As severe pollution occurs in autumn and winter, China had launched a half-year (October to March) action plan focusing on air pollution in autumn and winter in key areas like the Beijing-Tianjin-Hebei region and nearby regions, the Yangtze River Delta and the Fenwei Plain.

6. Comprehensive Emission Cut

Industrial Restructuring: China had been pushing ahead with pollutant emissions control of industrial enterprises. The intensity of pollutant emission in key industries in 2017 was down by more than 30 percent from 2012. Enterprises were promoted to transform and upgrade, speed up efforts to shut down backward production facilities, address overcapacity, and improve the industrial structure.

Pollution Control of "Fuel, Road, Vehicle": In September 2018, China issued the Three-Year Action Plan for Promoting Transportation (2018-2020), which clarified the targets of adjusting the

transport structure and vigorously developing railway transport. In 2018, China unified the standards for vehicle diesel, general diesel and some types of marine diesel. On Jan 1 of 2019, the National VI standard for vehicle gasoline and diesel came into force.

National Assessment on Acid Deposition in Indonesia

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[3]National Institute of Aeronautics and Space

Chapter 1. Basic Information on National Monitoring Activities

1.1 Outline

Indonesia initiated to participate in EANET activities since the preparatory phase. Acid deposition monitoring in Indonesia is implemented by observing wet and dry deposition, and attempted in assessing the impacts by monitoring soil, vegetation, and inland aquatic water. These tasks are conducted by various related national agencies which is Ministry of Environment and Forestry (MoEF) of Indonesia as National Focal Point (NFP), while Research and Development Center of Environmental Quality and Laboratory (P3KLL)/Environmental Management Center (EMC) - MoEF as the National Center (NC). The participating institutions are Meteorological Climatological and Geophysical Agency (BMKG), Center of Atmospheric Science and Technology - National Institute of Aeronautics and Space (PSTA-LAPAN), Research Center for Water Resources (RCWR) - Ministry of Public Work and Housing, and also Soil Research Institute (SRI)/BBSLDP - Ministry of Agriculture.

1.2. Monitoring program of acid deposition

Acid deposition monitoring program in 2015-2019 were performed to maintain the previous and current activities and further, and we plan to increase the number of EANET monitoring sites in Indonesia. Due to several alteration in the main task and function of the agencies, since 2015, EMC has undertaken the monitoring in all sites. No observation of annual vegetation monitoring during 2017-2019, as a result of technical and management issues.

Table 1 Monitoring sites in Indonesia

Location	Agencies	Monitoring interval
Serpong	EMC	WD: event, DD: biweekly (FP)
Bandung	LAPAN	WD: event, DD: biweekly (FP, PS)
Jakarta	BMKG Jakarta	WD: weekly, DD: biweekly (FP, PS)
Kototabang	BMKG Jakarta	WD: weekly, DD: biweekly (PS)
Maros	BMKG Jakarta	WD: weekly
Situ Patengan	EMC	IA: 4 times a year
Situ Gunung	EMC	IA: 4 times a year
Bogor	SRI	S: every 5 years

Note: *WD = wet deposition, DD = dry deposition, FP = filter pack, PS = passive sampler, IA = inland aquatic, S = soil*

1.2.1 Wet and dry monitoring

Besides Serpong and Bandung, wet deposition monitoring sites were mostly carried out under responsibility of BMKG Jakarta, as the national agency, in which, one of their basic tasks and functions is to provide the information of rain water quality all over the country. Following EMC Serpong, BMKG Jakarta and LAPAN Bandung established to monitor dry deposition using filter pack since April 2014. For ambient air quality, surface ozone observation in Bandung was implemented by LAPAN since 2015 using Dasibi Ozone Analyzer. $PM_{2.5}$ monitor was installed in BMKG Jakarta in 2016, however, there were some troubles on the equipment and $PM_{2.5}$ data started to be reported in 2017.

Table 2 Information of monitoring sites in Indonesia

Site	Classification	Latitude	Longitude	Altitude (m)
Serpong	Rural	06°21'01,9" LS	106°40'04,07" BT	64
Bandung	Urban	06°53'41,63" LS	107°35'11,31" BT	753
Jakarta	Urban	06°09'21,51" LS	106°50'32,67" BT	7
Kototabang	Remote	0°12'8.70"LS	100°19'4.50"BT	845
Maros	Rural	04° 59' 50.29' LS	119°34' 17.73" BT	1

1.2.2 Ecological impact monitoring

Figure 1. Ecological impact sites.

The sampling sites selected for inland aquatic monitoring are Situ Patengan, Bandung and Situ Gunung, Sukabumi in West Java Province. Monitoring frequency was 4 times a year. Situ Patengan is located in West Bandung, about 214 km from EMC Serpong the southeast (SE) and 52,8 km from LAPAN Bandung to the south west (SW). Situ Gunung is located in Sukabumi, about 135 km from EMC Serpong to the south southeast (SSE), while Dramaga Research Forest is 35 km to the south (S).

Soil monitoring was located in Dramaga, Bogor and conducted in every 5 years. Dramaga Research Forest which is covered an area of 60 ha was managed by the Center for Forest Research and Conservation, Ministry of Forestry. It has wet climate with average annual rainfall of 3940 mm, average temperature 24-28°C and humidity around 78-89%.

1.3 Sampling and measurement

1.3.1 Wet deposition

Table 3 Measurement and analytical methods of wet deposition

Site	Parameters	Method	Instrument
Serpong	pH	Glass electrode	HORIBA F-22
	EC	Conductivity cell	HORIBA Navi DS-52
	SO_4^{2-}, NO_3^-, Cl^-	Ion Chromatography	DIONEX ICS5000
	Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	Ion Chromatography	DIONEX ICS5000
Bandung	pH	Glass electrode	HORIBA F-51
	EC	Conductivity cell	WTW Inolab Cond Level 2
	SO_4^{2-}, NO_3^-, Cl^-	Ion Chromatography	DIONEX ICS 1500
	Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	Ion Chromatography	DIONEX ICS 1600
Jakarta/ Kototabang/ Maros	pH	Glass electrode	THERMO Electron Corp. ORION 3 Star
	EC	Conductivity cell	THERMO Electron Corp. ORION 3 Star
	SO_4^{2-}, NO_3^-, Cl^-	Ion Chromatography	DIONEX ICS 1600
	Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	Ion Chromatography	DIONEX ICS 1600

Wet deposition sample was collected using wet-only sampler. In EMC Serpong and LAPAN Bandung, rainwater was sampled on daily basis, and analyzed in laboratory. However, in BMKG Kototabang and Maros based on weekly basis. They measure pH and EC on site, then remained sample was stored into polyethylene bottle. Samples were preserved with biocide before they sent to BMKG Jakarta for further analysis. BMKG Jakarta also collected sample on weekly basis.

1.3.2 Dry deposition

A four-stage filter pack method was mainly applied for dry deposition monitoring in Serpong, Bandung, and Jakarta. BMKG Jakarta conducted the sampling and sent the samples to EMC Serpong for filter pack analysis. Monitoring of SO_2 and NO_2 by passive sampler were also conducted in Jakarta, Kototabang, and Bandung.

Table 4 Measurement and analytical methods of dry deposition

Site		Parameters	Method	Instrument
Serpong	FP	SO_4^{2-}, NO_3^-, Cl^-	Ion Chromatography	DIONEX ICS5000
		Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	Ion Chromatography	DIONEX ICS5000
Bandung	FP	SO_4^{2-}, NO_3^-, Cl^-	Ion Chromatography	DIONEX ICS 1500
	FP	Na^+, NH_4^+, K^+, Mg^{2+},	Ion Chromatography	DIONEX ICS 1600
	PS	Ca^{2+}	Ion Chromatography	DIONEX ICS 1500
	PS	SO_2	Spectrophotometry	Spectrophotometer
Jakarta/	PS	NO_2	Ion Chromatography	DIONEX ICS 1600
Kototabang	PS	SO_2	Spectrophotometry	Spectrophotometer
		NO_2		

1.3.3 Inland aquatic monitoring

Surface water were sampled directly by a clean polyethylene bucket every 4 times per year. Several physical and chemical parameters were measured on site using portable equipment, such as water temperature, water depth, clarity, water color, pH, EC, and DO. Since 2017, additional parameters were also conducted such as T-N, T-P, chlorophyll, and plankton identification.

Table 5 Measurement and analytical methods of inland aquatic

Site	Parameters	Method	Instrument
	pH	Glass electrode	HORIBA F-22
	EC	Conductivity cell	HORIBA Navi DS-52
Situ Patengan/	SO_4^{2-}, NO_3^-, Cl^-	Ion Chromatography	DIONEX ICS5000
Situ Gunung	Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	Ion Chromatography	DIONEX ICS5000
	Alkalinity	Titrimetric	Burette, pH meter

1.3.4 Soil monitoring

Soil sample from Dramaga Research Forest, Bogor were analyzed once every 5 years with measurement of pH(H_2O), pH(KCl), ex-Na^+, ex-K^+, ex-Ca^{2+}, ex-Mg^{2+}, ex-acidity, ex-Al^{3+}, and ex-H^+. All procedures were performed based on Technical Manual for Soil Monitoring in East Asia.

1.4 Inter-laboratory comparison

Indonesia participated in the Inter–laboratory comparison (ILC) project on wet deposition, dry deposition, inland aquatic, and soil, which involved 5 (five) laboratories.

Table 6 Inter Laboratory Comparison (ILC) Project in Indonesia

Agencies	Code	Type of ILC			
		Wet	Dry	IA	S
Research & Development Center of Environmental Quality & Laboratory/Environmental Management Center (EMC) – MoEF	ID01	√	√	√	√
Meteorological Climatological and Geophysical Agency (BMKG)	ID02	√			
National Institute of Aeronautics and Space (LAPAN)	ID03	√	√		
Research Center for Water Resources (RCWR)	ID04			√	
Soil Research Institute (SRI)	ID05				√

In case of data submission, EMC is responsible to compile, validate and submit the data from all respective agencies to the Network Center.

Chapter 2. State of Acid Deposition in Indonesia

2.1 Wet deposition

Wet deposition precipitation in Indonesia varied due to differences in the amount of annual rainfall. Figure 2. shows the total of annual precipitation ($mm.yr^{-1}$) in every monitoring site in 2015 to 2019.

The highest total annual average rainfall was Serpong (2,442.4 mm.yr^{-1}), followed by Kototabang and Maros.

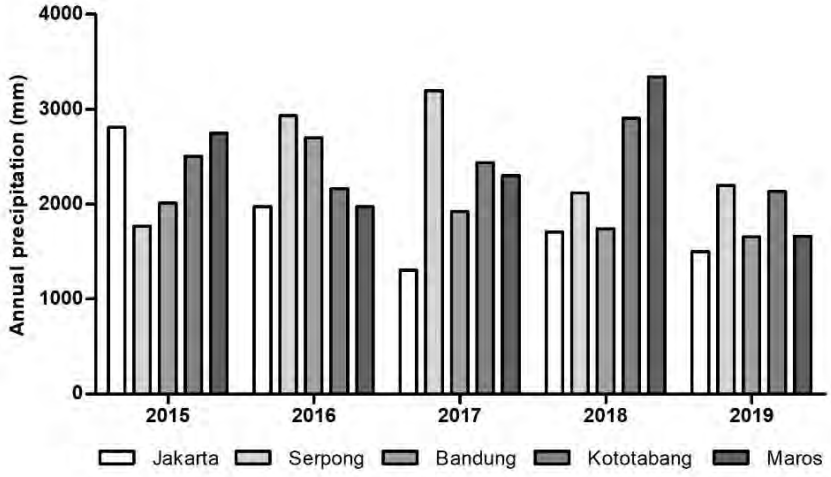
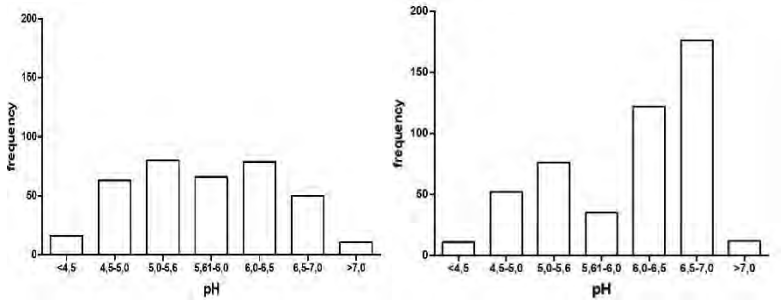


Figure 2. Annual precipitation in 2015-2019.

Figure 3. Annual average of pH in 2015-2019.

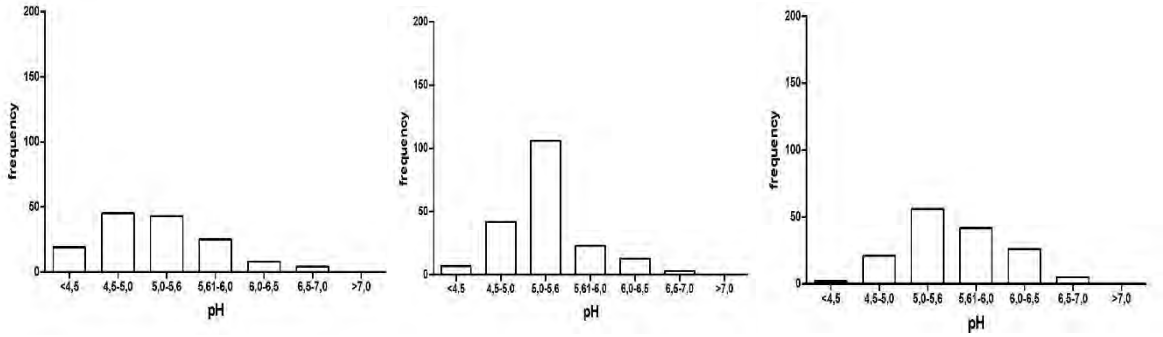
The average weighted pH for the period of 2015 to 2019 was shown in Figure 3. Average pH values in Indonesia are between 4.6 - 5.6. Low pH indicated that mostly all of sites were acidic. Jakarta as an urban area has a quite low annual average pH value, compared to other sites. The annual average of EC in all sites are varied from 0.4 – 3.0 mS m^{-1}.



(a) Serpong (b) Bandung

Figure 4. pH distribution in Serpong & Bandung during 2015-2019.

Sampling periode: event (data source: P3KLL Serpong & LAPAN Bandung)



(a) Jakarta (b) Kototabang (c) Maros

Figure 5. pH distribution in Jakarta, Kototabang & Maros during 2015-2019.

Sampling periode: biweekly (data source: BMKG Jakarta)

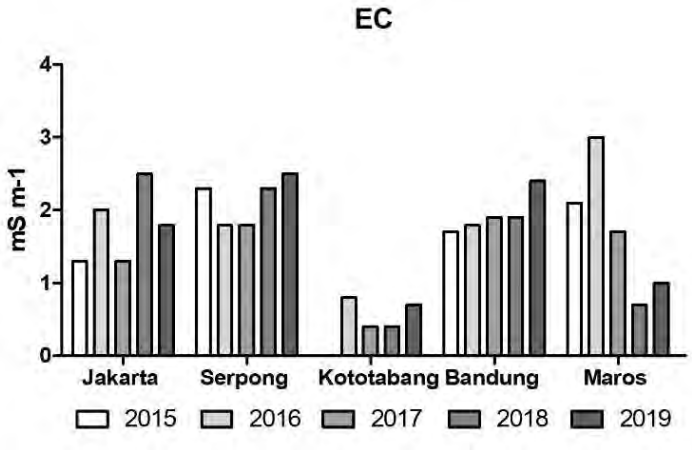


Figure 6. Annual average of EC in 2015-2019.

The following figures shows the characteristic of chemical rainwater in several sites based on average annual data for each parameter from year 2015 to 2019. In Serpong and Jakarta, NH_4^+ and NO_3^- were dominantly found, while in Bandung were NH_4^+ and nss SO_4^{2-}. Those NO_3^- and nss SO_4^{2-} in three sites were mostly influenced by anthropogenic activities such as fossil fuel combustion, while the source of NH_4^+ was possibly dominated by natural source. The characteristic of chemical composition in Kototabang and Maros was different from others. The dominant ions in Kototabang were nss Ca^{2+} and Cl^-, while in Maros were Na^+ and Cl^-.

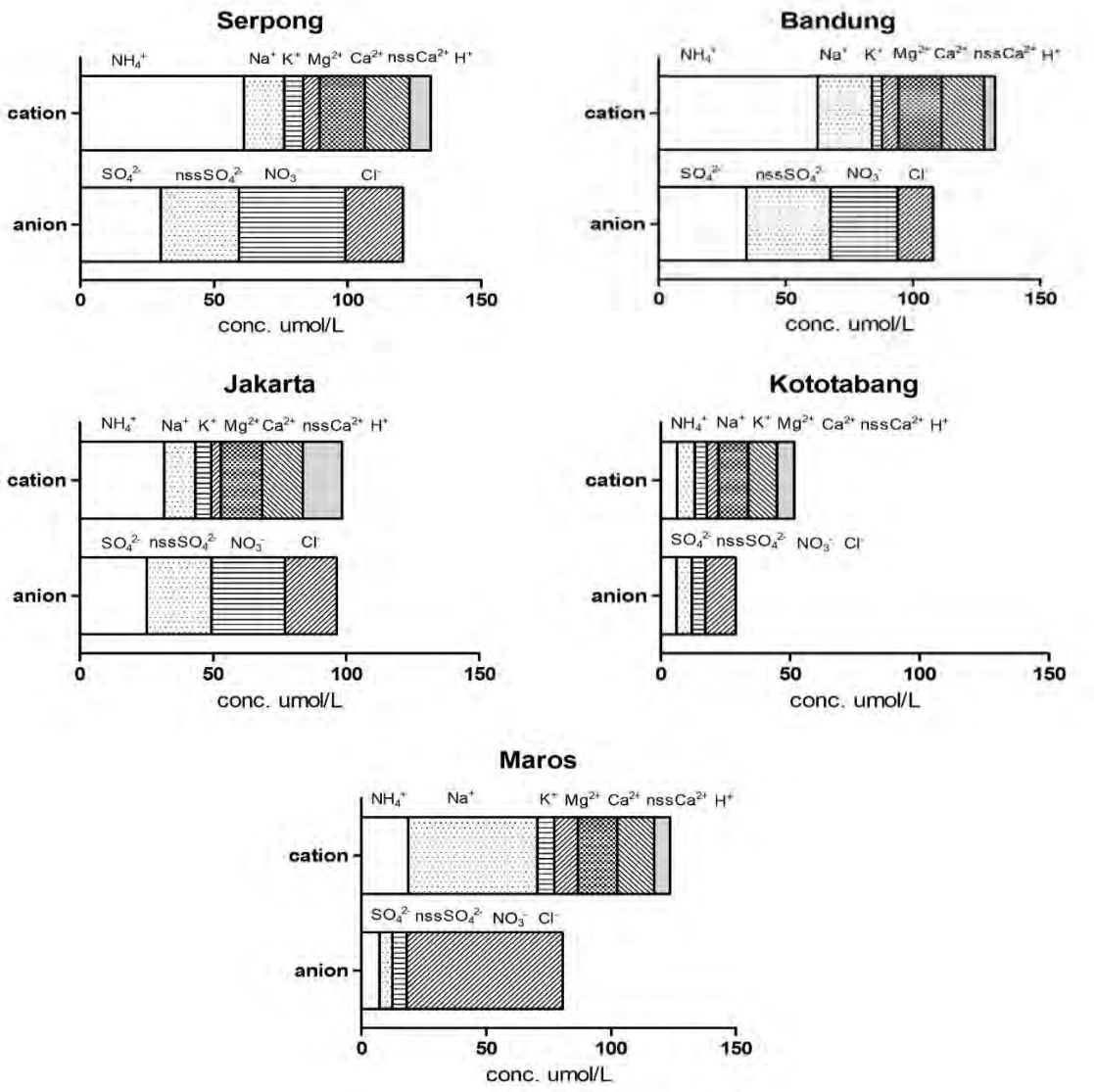


Figure 7. Chemical composition of rainwater in several sites from 2015 to 2019.

During STM 20th (2019), Indonesia proposed to include another BMKG monitoring sites into EANET activities to represent the central part of Indonesia. They are station of Climatology Class II BMKG – Jembrana, Bali Province, located at 08º20'26.67"S 114º37'01.53"E and Station of Climatology Class I BMKG – Lombok Barat, West Nusa Tenggara Province, located at 08º38'10.4"S 116º10'15.0"E. Both were classified as rural area. The annual pH in Jembrana and Lombok Barat in 2019 were 5.39 and 5.59, respectively.

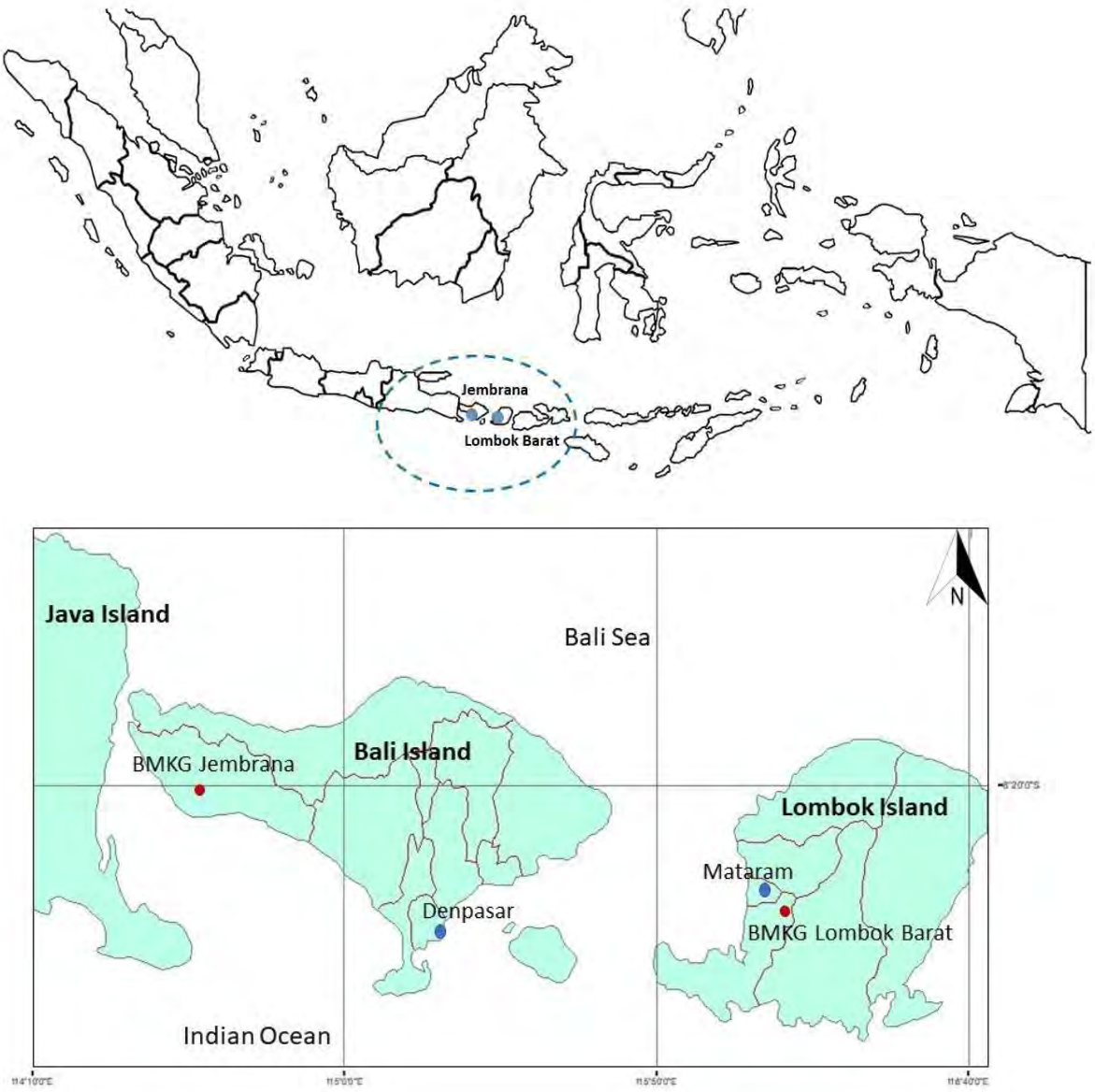


Figure 8. Map of Bali and Lombok Island.

(a) Lombok Barat

(b) Jembrana

Figure 9. New sites of wet deposition.

2.2 Dry deposition

Dry deposition monitoring was carried out using the filter pack and passive sampler methods. Filter pack consists of gases and aerosol, where the parameters for gases of SO_2, HNO_3, HCl and NH_3, and aerosols of SO_4^{2-}, NO_3^-, Cl^-, Na^+, NH_4^+, K^+, Mg^{2+} and Ca^2 These gases and particles composition contributed to the formation of acid deposition. Monitoring of dry deposition in Indonesia for filter packs were carried out in Jakarta, Serpong, and Bandung. The results of monitoring dry deposition using a filter pack for gas and aerosols from 2015 – 2019 were described in Figures as follow:

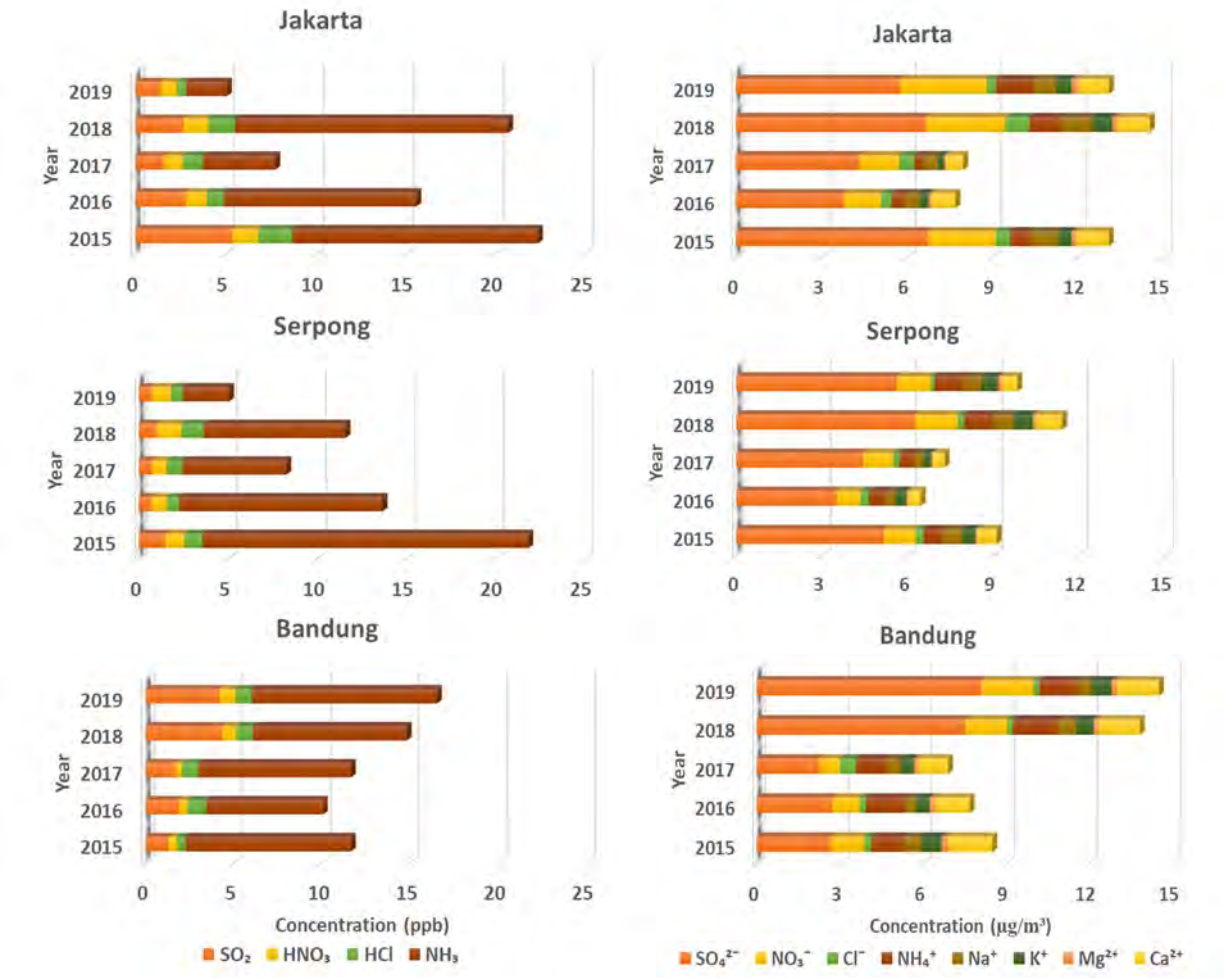


Figure 10. Annual concentration of gas and aerosol in filter pack.

Based on Figure 10., it appears that the concentration of both gas and aerosols for Bandung has increased from 2015 - 2019. As for Jakarta and Serpong, they showed a significant decrease in gas concentrations from 2015 - 2019. However for aerosol concentrations, Jakarta and Serpong from 2015 - 2019 showed fluctuations in concentration from year to year. The reduction in gas concentrations for Jakarta and Serpong is due to the impact of the implementation of a Governor Regulation on public transportation, including the use of gas fuel, also contributed to the improvement in air quality in Jakarta and Serpong.

In addition, the result of passive sampler monitoring data in Jakarta, Bandung, and Kototabang was described in Figure 11. Concentration of SO_2 in Jakarta were higher compared to Bandung and Kototabang. On the other hand, NO_2 in Bandung has a higher concentration than two other sites, because the monitoring location is near the road with daily heavy traffic. Based on research, the traffic density of motorized vehicles in Bandung contributed the highest pollution both for concentrations of particulates, NOx and CO. Kototabang as a background area has a low level of NO_2 and SO_2.

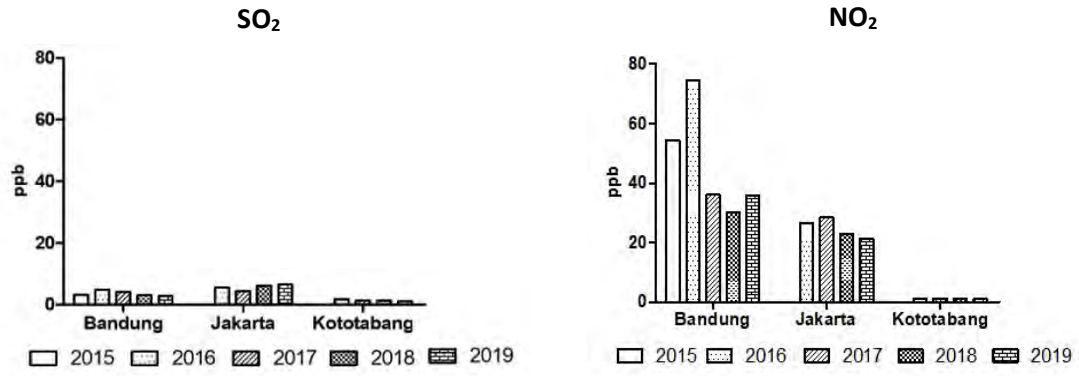


Figure 11. Annual concentration of SO_2 and NO_2 in passive sampler.

Moreover, the result of ozone monitoring in Bandung and $PM_{2.5}$ monitoring in Jakarta are shown in following figure:

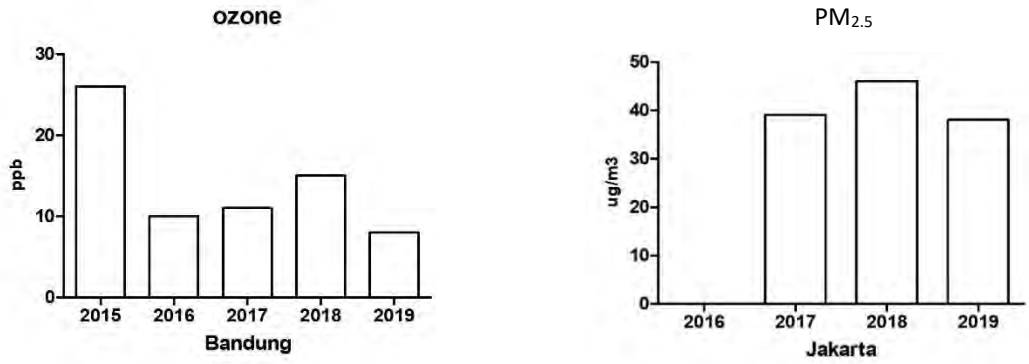


Figure 12. Annual concentration of ozone and $PM_{2.5}$.

2.3 Inland aquatic

Started in 2015, EMC conducted the inland monitoring in both sites, Situ Patengan and Situ Gunung, West Java Province. Based on monitoring, the physical lake water quality showed that average daily temperature was 22ºC in Situ Patengan. The color of water was clear and greenish, water clarity was range from 0.2 to 2.0 m, and the depth varied from 2.3 to 9.0 m depend on the sampling season. In Situ Gunung, the color of water was clear and brownish, water clarity was range from 0,75 to 1,7 m, and the depth varied from 1,4 to 2,8 m.

Situ Patengan, Bandung

Situ Gunung, Sukabumi

Figure 13. Inland aquatic monitoring sites.

The pH of Situ Patengan range from 7.3 to 8.1, while in Situ Gunung is 7.4 to 8.0. Although the rainwater pH in Bandung area was potentially indicated the acid deposition phenomenon, the impact of acidity itself on Situ Patengan has not yet apparent. The pH of both lakes are still within the range of normal standard condition of inland aquatic (pH 6-9) in Indonesia, based on government regulation Government Regulation No 22/2021 Attachment VI. The electrical conductivity in Situ Patengan and Situ Gunung shown the amount below 10 $mS.m^{-1}$, while alkalinity values have exceeded the maximum limit (>0.2 $meq.l^{-1}$). The average concentration of dominant ions were 9.6 mg/L of SO_4^{2-} and 6.4 mg/L of Ca^{2+} in Situ Patengan, while 7.4 mg/L of SO_4^{2-} and 6.6 mg/L of Ca^{2+} in Situ Gunung.

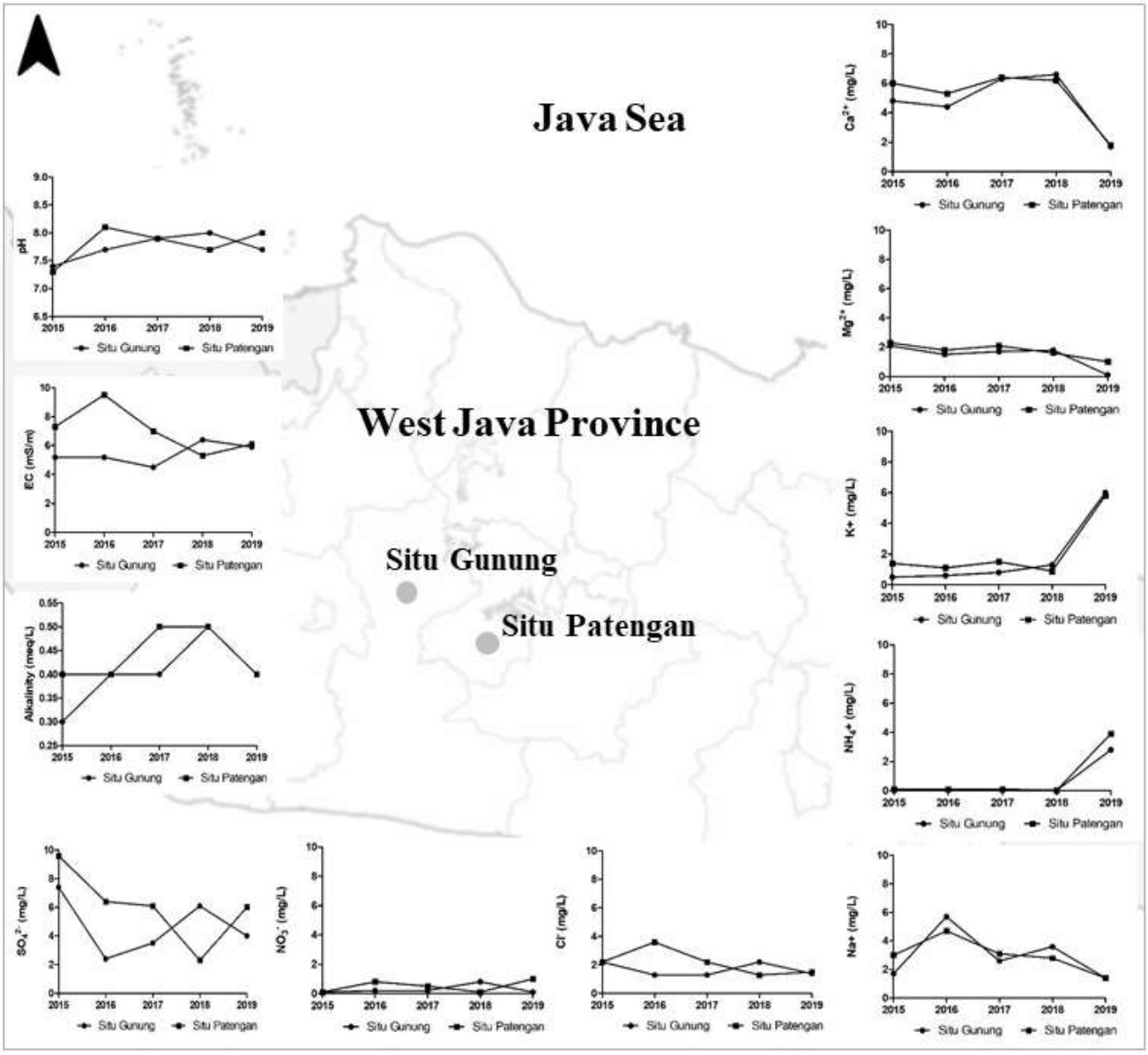


Figure 14. Inland aquatic monitoring in Indonesia 2015-1019.

2.4 Soil and vegetation

Soil monitoring was conducted every 5 years in Dramaga Research Forest, Bogor - West Java Province, which is managed under the Forest and Nature Conservation Research and Development Center, Ministry of Forestry.

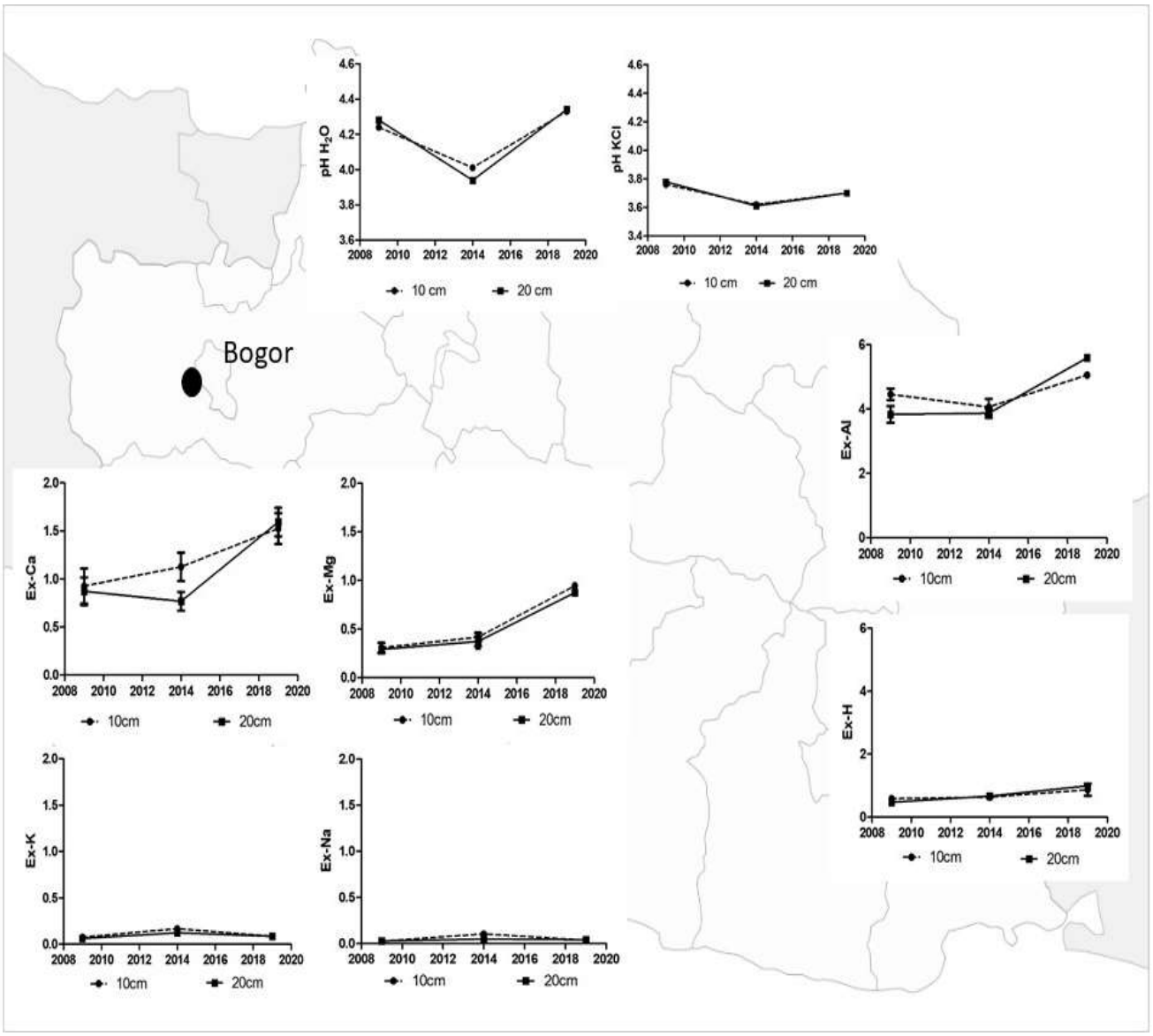


Figure 15. Soil monitoring in Indonesia 2010-2019.

Figure above described the soil chemistry monitoring in the observation period of 2009, 2014 and 2019. The type of soil has a very acid pH, low organic matter, exchangeable-cation and cation exchange capacity (CEC), so it is considered as poor soil. Exchangeable cations in soil samples was dominated by exchangeable-Ca (Ex-Ca), followed by exchangeable-Mg (Ex-Mg) and exchangeable-Na (Ex-Na) is the smallest such as generally normal land. There has been no extreme change during the observation in year 2001-2019.


Figure 16. Soil and vegetation monitoring in Indonesia.

Vegetation monitoring also has been conducted in Dramaga Research Forest (block 12) Bogor (GPS located at 106°44'55.1" E and 6°33'7" S) from 2008-2016. From the tree measurement in 2016 as shown in Table 7. there were some dead trees. However, there is no clear indication of direct impact of acid deposition. The estimated cause of decline was pest and very dense. Tree number 1(71), 12(269), 16(113) and 51(294) were fallen due to hard rain and strong wind.

Table 7 Observation of trees declines in Dramaga (2016)

Individual No.	1 (71)	4 (27)	5 (279)	6 (280)	8 (282)	12 (269)	16 (113)	21 (83)	23 (146)	27 (175)	28 (232)	31 (264)	33 (266)	34 (267)	39 (275)	42 (278)	44 (287)	46 (289)	49 (292)	51 (294)
Direction	N	N	N	N	N	E	E	E	E	E	S	S	S	S	S	W	W	W	W	W
Plant Name	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*	*Melia excelsa*	*Maesopsis emenii*	*Hopea mengaravan*	*Hopea odorata*	*Khaya grandifolia*	*Hopea mengaravan*	*Hopea mengaravan*	*Hopea mengaravan*
Relative height																				
Tree height (m)	28	33	40	43	45	30	24	47	31	7.5	42	10	6.5	5.8	43	30	45	42	35	40
Vitality of tree				1								1	2	1			2	1	1	
Form of tree		2		1	2			2	1	1	1		3	1	1	1	1	2	1	
Branch growth		2		1	2			2	2	1	2		2	2	1	2				
Dieback of stem		1							1					1		1				
Defoliation of crown		1							1				1	1	1	1		1	1	
Deformation of leaves																				
Density of foliage		1							2				2	2	1	1		2	1	
Size of leaves																				
Discoloration of leaves									1				1	1						
Injury of leaves									1				1	1						
Damage class		1							1	1			1	1	1	1		1		1

Chapter 3. Review of National Air Quality Management including Acid Deposition

Ministry of Environment and Forestry supported the grand design of air pollution control by regulating the stationary and mobile sources. Regulations related to air pollution control are mostly based on Government Regulation No 41/1999 for Control of Air Pollution (ambient) and State Minister of Environmental Decree No 13/1995 for Stationary Sources.

During 2015-2019, MoEF revised the emission standards of stationary sources by reducing the maximum limit of parameters, mostly for total particle, SO_2, and NO_X in cement (Minister of Environment and Forestry Decree No.19/2017), power plant (Minister of Environment and Forestry Decree No.15/2019), along with fertilizer and ammonia industry (Minister of Environment and Forestry Decree No.16/2019). Flue gas desulphurization were applied to reduce the sulphur and particulate emission. The industries of cement, fertilizer, iron & steel making, and carbon blank are requested to install the integrated and online continuous monitoring system.

In case of mobile sources, the implementation of Euro 4: Minister of Environment and Forestry Regulation No 20/2017 is aimed to benefit all sectors. For car manufacturers, they do not require to do a further products customization in order to export, and for society the people will get high quality vehicles with better emission standards. Those actions are supposed create a better urban air quality. MoEF also propose to promote national energy planning for transport sector, such as to develop mass public transportation system, to improve transport management by developing intelligent transport system in 24 cities and area traffic control system in 50 location, to accelerate mass transport development and private car to use gas fuel, and to develop policy regarding utilization of diesel fuel for transportation and their facilities.

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EANET, 2006, Periodic Report on the State of Acid Deposition in East Asia Part II: National Assessment, November 2006, Niigata, Japan

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National Assessment Report for Japan

Chapter 1. Basic Information on National Monitoring Activities

1.1 Outline of activities on acid deposition and air pollution in National Monitoring Plan

The acid rain problem in Japan, which was first recognized as moist air pollution in the 1970s, has been transformed into a wider environmental problem, because of the increase in air pollutant emissions due to the rapid economic development of the East Asian region and concerns about their transportation to Japan, which is located on the leeward side of the Asian continent. Based on the fact that acid rain has a serious impact on ecosystems such as lakes and forests in Europe and the United States, the Ministry (agency) of the Environment, Japan started the first acid rain countermeasure survey in 1983 in the fields of air, soil / vegetation, and inland water to understand the actual status of acid rain in Japan. The results of the 20-year survey up to 2002 were compiled in June 2004 as the "Acid Rain Countermeasures Survey Comprehensive Report". The report revealed the following: 1) Acid rain similar to that in Europe and the United States is observed nationwide. 2) Inflow of pollutants originating from the continent is suggested in the area on the Sea of Japan side. 3) Changes in physics and chemistry that are suspected to be affected by acid rain are observed in the rivers flowing into Lake Ijira and the surrounding soil. In addition, in order to continuously carry out wide-area and long-term acid rain monitoring, the "Acid Rain Long-term Monitoring Plan" has been formulated since 2003 and implemented. This result was summarized in the "Acid Rain Long-Term Monitoring Report (2003-2007)". Among them, it was pointed out that it is necessary to elucidate the acidification process in the Ijira Lake catchment area and to monitor transboundary air pollution by integrating ozone and particulate matter.

On the other hand, in the East Asian region, the "Acid Deposition Monitoring Network in East Asia (EANET)" led by Japan started its regular phase activity in January 2001 in order to promote acid rain countermeasures based on international cooperation (currently, 13 countries participated). At EANET, the monitoring of wet and dry deposition, soil and vegetation, inland aquatic environment and catchment-scale is currently being continuously carried out by participating countries at more than 100 sites in the East Asian region by an unified method. The network center established in Japan is in charge of quality control of the monitoring and data aggregation, and the data reports and the inter-laboratory comparison survey reports between analytical institutions are published every year by the network center. In addition, the "Periodic Report on the State of Acid Deposition in East Asia" (PRSAD) is published every five years. At EANET, monitoring of acid deposition and its effects is underway, but discussions are being held not only on acid deposition but also on the possibility of broadly targeting air pollution problems.

In response to this growing interest in transboundary air pollution issues at home and abroad, Japan established "Transboundary Air Pollution / Acid Rain Long-Term Monitoring Plan" in March 2009. In the plan, it is clarified that the transboundary air pollution monitoring should be carried out not only for acid deposition but also for ozone and particulate matter. The plan is to grasp the long-distance transboundary transportation and long-term trends of air pollutants such as precursor of acid

deposition and ozone, and to grasp the effects of transboundary air pollution and acid deposition at an early stage and predict future effects. The purpose is to carry out long-term atmospheric and ecological impact monitoring in close cooperation with EANET. According to the report of the survey (March 2014) conducted from 2008 to 2012, the acidity of precipitation in Japan still tends to be high. Regional differences in gaseous and particulate matter concentrations and seasonal fluctuations still suggest the effects of transboundary pollution from the continent. In addition, secular changes suggesting a relationship with atmospheric deposition such as a decrease in pH of soil and river water were observed at some sites, and areas requiring monitoring of plant effects due to ozone were also extracted.

Table 1 shows the number of monitoring sites in each survey from FY*1983 to FY2012.

This report focuses on the results of monitoring conducted in FY2013-FY2017.
*: The fiscal year in Japan is from April 1st to March 31st. (Hereinafter indicated "FY" in front of year as appropriate.)

Table 1 Number of monitoring sites in each survey

Survey	First	Second	Third	Fourth	—	Long-term	
Period (FY)	1983-1987	1988-1992	1993-1997	1998-2000	2001-2002	2003-2007	2008-2012
Wet/Dry Deposition	14~34	29	48	55	48	31	27
Soil /Vegetation	12	43	88	20	18	25	25
Inland aquatic environment	133 (Screening survey)	5	33	17	12	11	11
Catchment -scale						1	1
Others		2(Snow)					

1.2 Monitoring program from FY2013 to FY2017

1.2.1 Introduction

The Ministry of the Environment Government of Japan (MOEJ) * has been conducting acid deposition monitoring since 1983. From the viewpoint of clarifying that ozone and aerosols should be monitored as transboundary air pollutants as well as SO_2, NOx, etc., wet deposition (precipitation), dry deposition including air pollutants, such as gases and aerosols, soil and vegetation, inland aquatic environment and catchment-scale monitoring are currently implemented according to the Long-Term Monitoring Plan (revised in March 2014). This report is compiled the monitoring results for the five years from FY2013 to FY2018.
*: The original organization was the Environment Agency of Japan until 2001.

1.2.2 Objectives of tranboundary air pollution and long-term acid deposition monitoring

Atmospheric and ecological impact monitoring are carried out for a long period of time in close

collaboration with the Acid Deposition Monitoring Network in East Asia (EANET);

- To understand long-distance transboudary transportation and long-term trends of air pollutants, such as acid rain precursors, ozone and $PM_{2.5}$, etc.and
- To early grasp the effects of transboundary air pollution and acid deposition and predict their future effects.

1.2.3 Detailes of monitoring

Wet and dry deposition monitoring were carried out to understand the status of acid deposition. Soil and vegetation, inland aquatic environment, and catchment-scale monitoring were carried out for clarifying the impact by acid deposition. (Table 2)

Table 2 Transboundary Air Pollution and long-term acid deposition monitoring (From FY2013 to FY2017)

	Classification	Monitoring content	The number of sites
Acid Deposition Monitoring	Wet deposition monitoring	Monitoring precipitation pH (both rain and snow) and concentrations of dissolved ionic components in precipitation, which includes calculating deposition amounts on the ground surface by multiplying each ionic concentration with its precipitation amount.	24 (27 sites in FY2013)
	Dry deposition monitoring	Monitoring air concentrations of gaseous substances, gravimetric concentrations of particulate matters and their constituents. Calculating of deposition amounts on the ground surface based on meteorological conditions such as wind speed.	
Ecological Impact monitoring	Soil and vegetation monitoring	Monitoring soil condition, including pH and ionic concentrations, as well as the degree of tree decline and understory vegetation.	25
	Inland aquatic environment monitoring	Monitoring pH and ion concentrations in rivers, lakes, etc.	11
	Catchment-scale monitoring	Monitoring to evaluate mass balance between acidic substances through the atmosphere or in/out flow river and its effect on the ecosystem focusing on a certain watershed (catchment).	1

Chapter 2. Acid Deposition and Air Pollution in Japan and Their Environmental Impacts

2.1 State of acid deposition and air pollution

2.1.1 Precipitation acidity (pH)

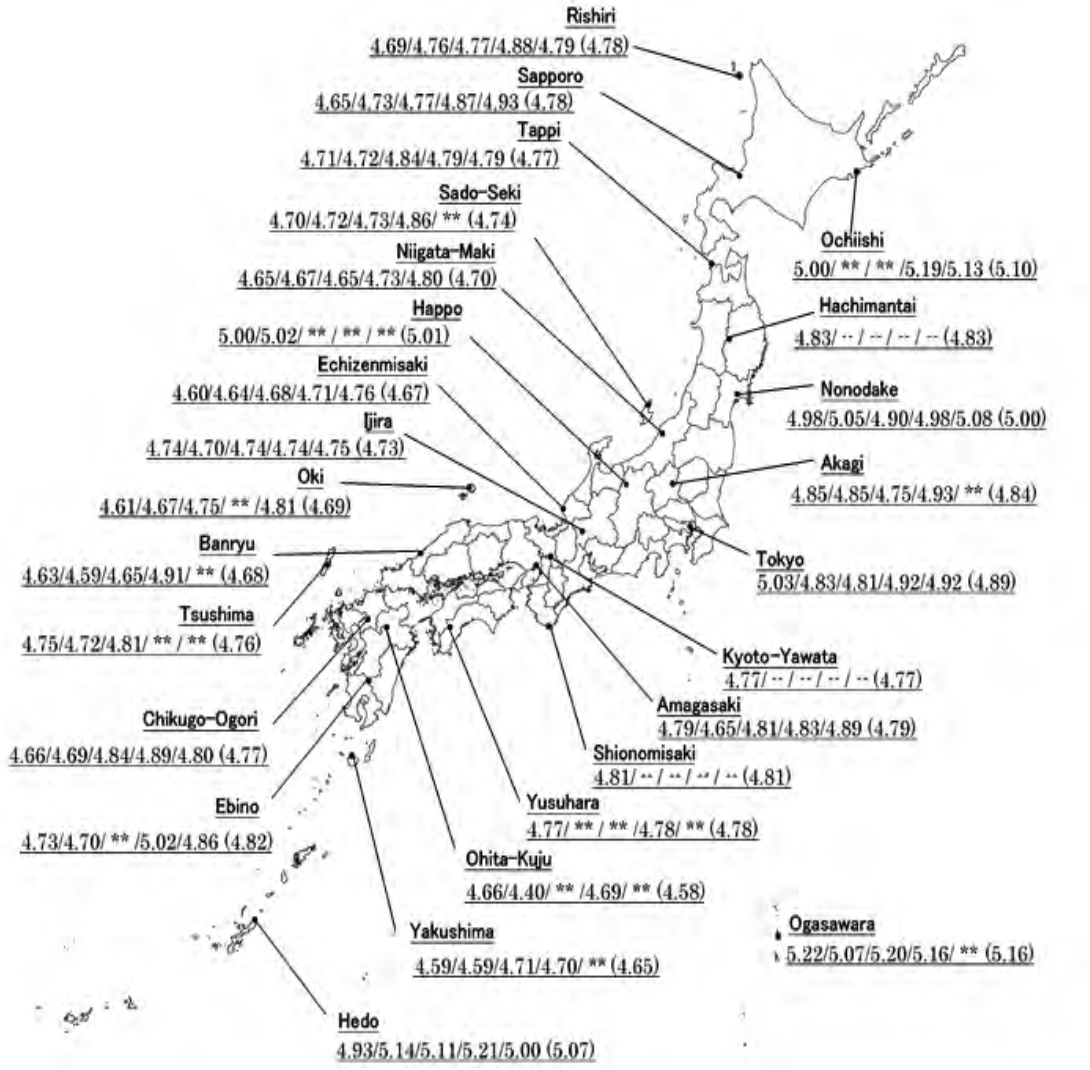
Precipitation acidification has continued in Japan showing pH lower than in Europe, the United States and EANET countries other than Japan. However, in recent years, precipitation pH has shown signs of rising (decreasing acidity) in Japan as China's air pollutant emissions are reduced.

- The 5-year (FY2013-FY2017) averages of precipitation pH at each site in Japan were in the range of pH 4.58-5.16. It was relatively high in Ogasawara (5.16), Ochiishi (5.10), and Hedo (5.07),

and relatively low in Ohita-Kuju (4.58), Yakushima (4.65), and Echizenmisaki (4.67). The 5-year average of precipitation pH in all sites was 4.77, and it can be recognized that precipitation is still acidified (Figure 1).

- Precipitation pH in Japan is lower than their average values in Europe, the United States and EANET countries (Cambodia, China, Indonesia, Laos, Malaysia, Mongolia, Myanmar, Philippines, South Korea, Russia, Thailand, Vietnam) excluding Japan (Figure 2-1). Comparing the contribution of acid that acidifies precipitation and the contribution of base that neutralizes precipitation between regions using the median of each network, both the sum of acid concentration and the sum of base concentration in Europe and the United State are almost equal, and the sum of base concentration is larger than that of acid concentration in EANET countries other than Japan. The sum of base concentration in Japan is about half that of acid concentration, that is a reason why precipitation pH in Japan is low. (Figure 2-2).

- In recent years, the emission amount of sulfur and nitrogen oxides in China has been decreasing, so it is considered that the contribution of acid to precipitation in Japan is also on a downward trend. As a result, Japan's precipitation pH has also shown signs of rising (Figure 3).



FY2013/FY2014/FY2015/FY2016/FY2017 (5-year average)

-- : No measurement

**: The annual average did not meet the validity criteria and was rejected.

Note 1: The annual average was calculated as precipitation amount weighted mean. But each value in parentheses shows their 5-year arithmetic average, as well as the all-sites' average.

Note 2: Hokkaido area; Rishiri, Sapporo, Ochiishi, Pacific Ocean side; Hachimantai, Nonodake, Akagi, Ijira, Tokyo, Ogasawara, Shionomisaki, Yusuhara, North of Japan; Tappi, Sado-seki, Niigata-Maki, Happo, Echizenmisaki, Kyoto-Yawata, Seto Island Sea Coast; Amagasaki, Ohita-Kuju, San'in ; Oki, Banryu, East China Sea Coast; Chikugo-Ogoori, Tsushima, Ebino, Nansei Iskands;Yakushima, Hedo. Hachimantai, Kyoto-Yawata, and Shionomisaki sites stopped monitoring in FY2013.

Figure 1. Distribution of Precipitation pH in Japan (FY2013-FY2017) .

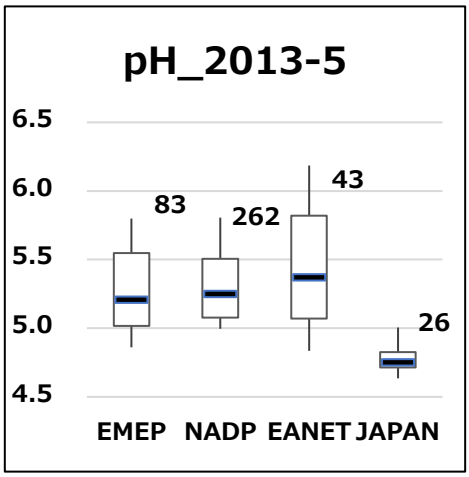


Figure 2-1. Comparison of precipitation pH between Japan and the other international networks (EMEP[1]: Europe, NADP[2]: North America, EANET: East Asia except Japan).
Distribution of precipitation weighted average of pH from 2013 to 2015 (FY2013-FY2015 in Japan) at the sites comprising each network. Their values beside each bar in the figure are the number of sites. Box plots represent the 10, 25, 50, 75, and 90th percentile values[3] for each network data.

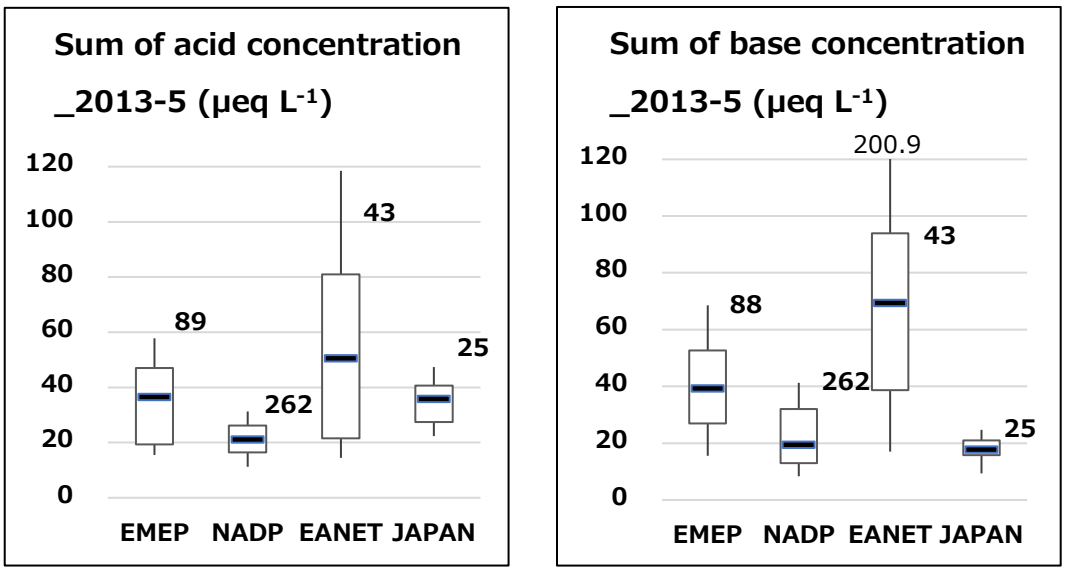


Figure 2-2. Comparison of the sum of acid concentrations (left) and the sum of base concentrations (right) between each network.
Sum of acid concentration represents non-sea salt sulfate ion (nss-SO_4^{2-}) plus nitrate ion (NO_3^-), sum of base concentration represents ammonium ion (NH_4^+) plus non-sea salt calcium ion (nss-Ca^{2+}) (Both are equivalent concentrations). Description of the numbers in the figure and box plots are the same as Figure 2-1.

[1] EMEP: Co-operative Program for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
[2] NADP: National Atmospheric Deposition Program
[3] The percentile value is a value located at a specified percentage of the total when the target data groups are arranged from the smallest.

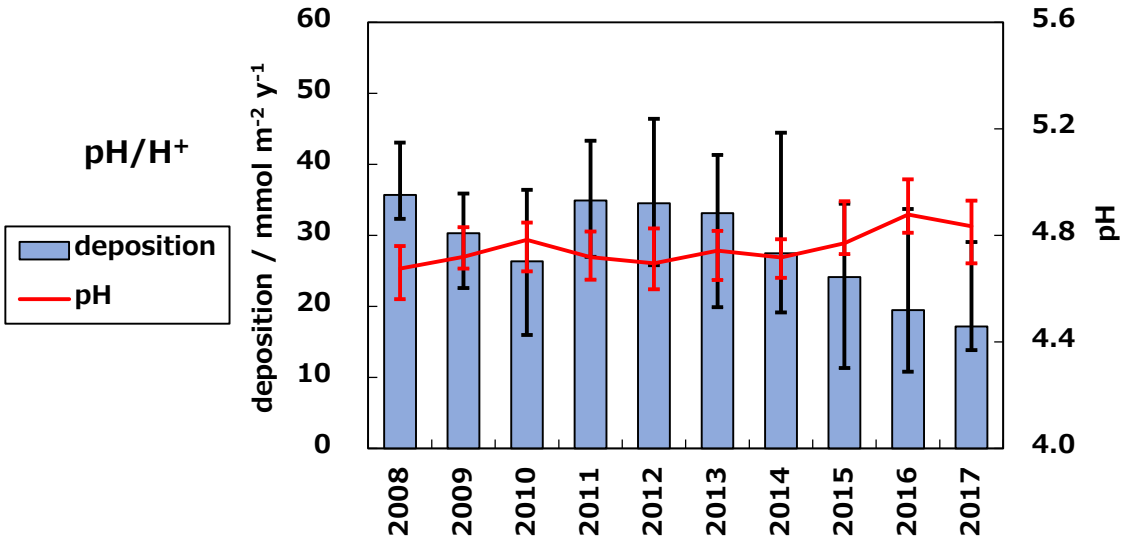


Figure 3. Annual variation of precipitation pH and hydrogen ion (H^+) deposition (median) in the last ten years.

Error bars mean the range of 25th to 75th percentile values for each year in pH and hydrogen ion deposition. The annual data which did not meet the criteria of completeness[4] are not included in calculation.

2.1.2 Seasonal variations of substance in precipitation

Concentrations, such as non-sea salt sulfate ion, contained in acidified precipitation, show a remarkable increase in winter at San'in area which is close to the continent, suggesting influence from the continent in addition to domestic sources.

- When the concentrations of nss-SO_4^{2-}, NO_3^- and NH_4^+ in precipitation were examined by region all over Japan, they showed almost the same seasonal variations, and tended to be low in summer and high in winter as a whole. Since San'in area and North of Japan sea area are close to the continent, they are easily affected, and a significant increase is seen in winter compared to the other regions, suggesting influence from the continent in addition to domestic sources. (Figure 4)

[4] Completeness means the ratio of valid data for a certain monitoring period.

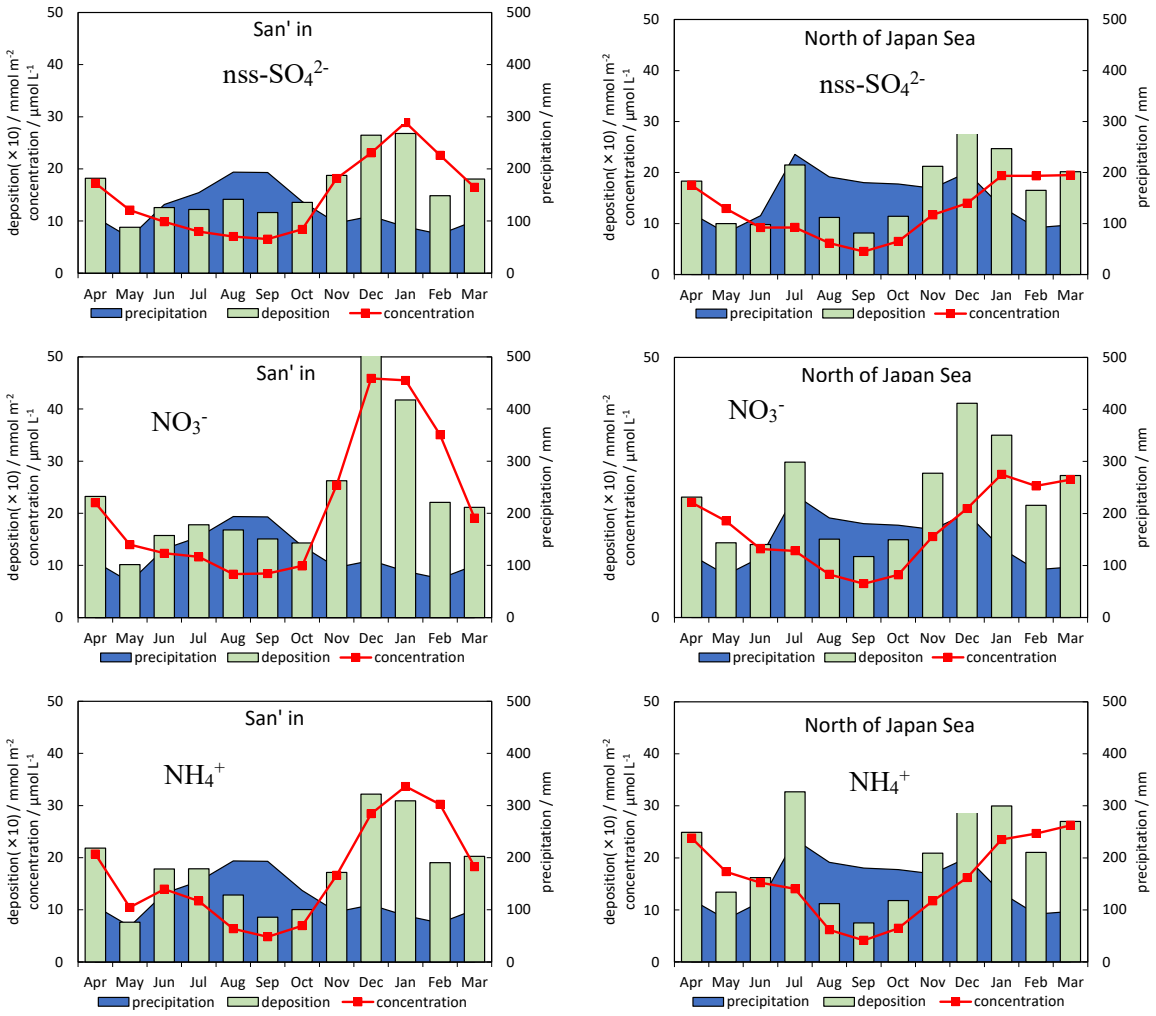


Figure 4. Seasonal variations in nss-SO_4^{2-}, NO_3^- and NH_4^+ concentration, deposition and precipitation at San' in area and North of Japan sea area (FY2013 – FY2017).

2.1.3 Seasonal variations of air pollutant concentrations

Their seasonal variation tendency of air pollutants (gases and aerosols) differs depending on substances, and the concentrations of sulfur dioxides were high in winter, suggesting the effect of advection from the continent by the northwest monsoon. The concentrations of ozone and particulate matters were high in spring, suggesting that ozone was advected from the continent as well as dropped from the stratosphere and particulate matter was affected by flying yellow sand.

- As shown in Figure 5, the seasonal variations of air pollutants (gases and aerosols) with respect to the monthly average concentrations for 5-year from FY2013 to FY2017 vary depending on substances. The detailed explanations for each substance are shown as follows.

- Sulfur dioxide (SO_2): The overall trend of SO_2 concentrations is lower in summer and higher in winter, suggesting the influence of advection from the continent. Although other meteorological factors, such as the height of boundary layer, are considered to be influence factors for the atmospheric concentration, the monsoon from the continent in winter seems to be the dominant

factor.

On the other hand, high concentrations were observed in Yakushima, Ebino, and Yusuhara, which were thought to be of volcanic origin. It is suggested that Yakushima, which is located in the volcanic islands of the Satsunan Islands, may have been affected by eruptions of neighboring islands, and that Ebino and Yusuhara may also have been affected by nearby volcanoes.

- Nitrogen oxides (NOx*): On the whole, there was no consistent trend, but the trend was different for each site, for example, at Ijira, it was high in summer due to transportation from the Chukyo metropolitan area, while at Yusuhara, it was high in winter.

- Ozone (O_3): In general, O_3 concentrations tend to reach a maximum in spring and to be lower in summer. In the spring season, ozone advection from the continent and ozone fallout from the stratosphere are considered to be their main causes, while in the summer season, reduced ozone concentrations by the inflow of oceanic air have been pointed out. The results of source contribution analysis using an air quality model indicate that the contribution of ozone advection is larger in spring.

- Particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$): The mass concentrations of PM_{10} and $PM_{2.5}$ tended to be high in spring as a whole, suggesting that the influence of flying yellow sand is significant.

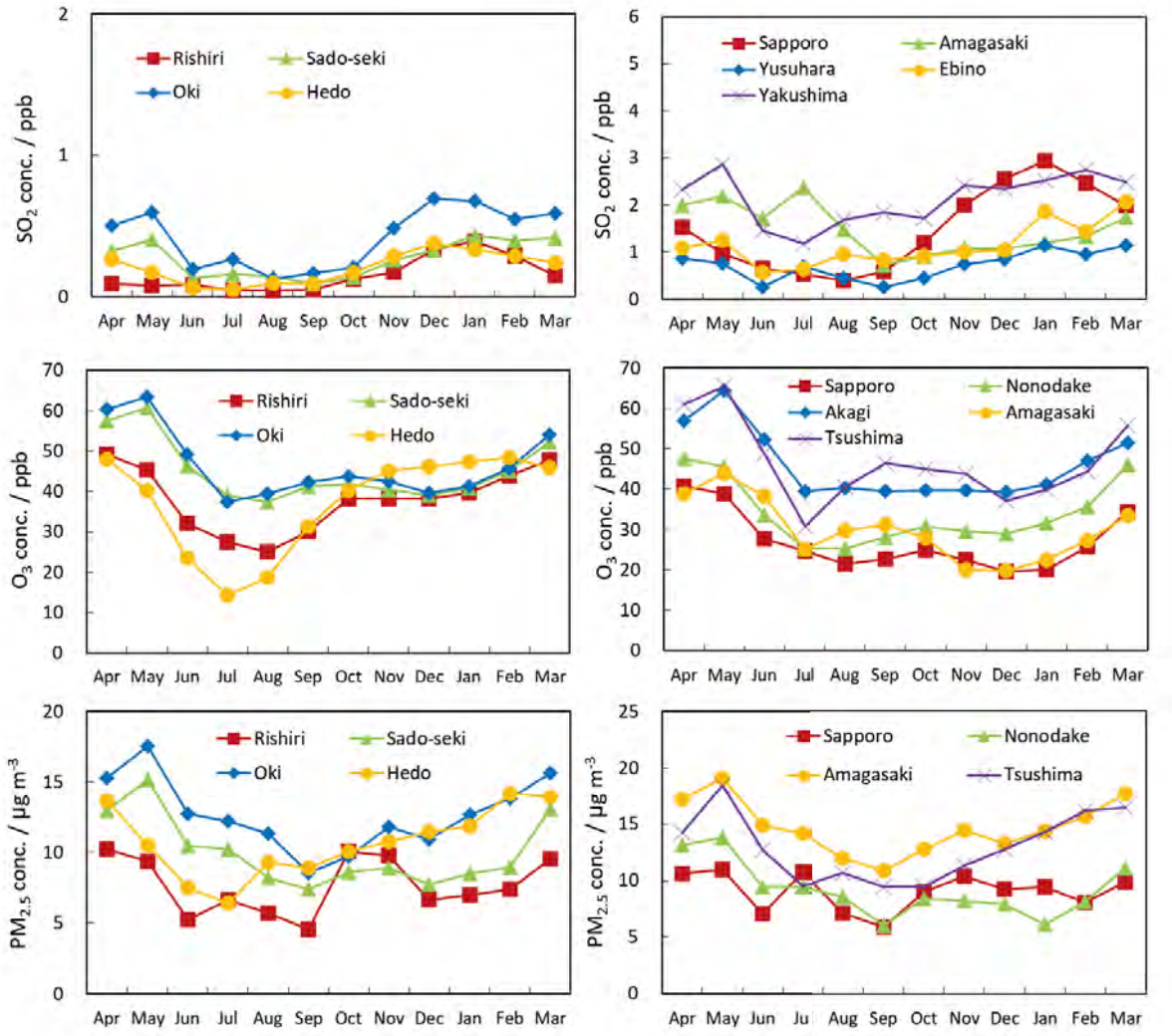


Figure 5. Seasonal variations of SO_2, O_3 and $PM_{2.5}$ concentrations (5-year monthly average for FY2013- FY2017). Monthly values with less than 70% completeness were not included in the calculation.

2.1.4 Long term trends of air pollutant concentrations (Except ozone and PM)

The concentrations of SO_2 and particulate nss-SO_4^{2-} in the atmosphere tended to be continuously high at the sites in western Japan which are close to the continent, suggesting that the contribution of advection from the continent was larger at these locations.

- Figure 6 shows annual variations (FY2008-FY2017) of SO_2 and particulate nss-SO_4^{2-} concentrations. Regarding SO_2 concentrations, in remote areas along the Sea of Japan (i.e., at a sufficient distance from domestic sources), Oki in the west, which is closer to the continent, tended to have continuously higher concentrations than those of Sado-Seki, and particulate nss-SO_4^{2-} concentrations tended to be higher in western Japan than that in eastern Japan, suggesting that the contribution of advection from the continent was greater in western Japan.

- The concentrations of SO_2 and particulate nss-SO_4^{2-} showed decreasing trends in the last five years, reflecting the decreasing trend of SO_2 emissions in the continent.

- Among the remote sites, the SO_2 concentrations in Yusuhara, Ebino, and Yakushima were relatively high, which is possibly caused by SO_2 emission due to volcanic activities.

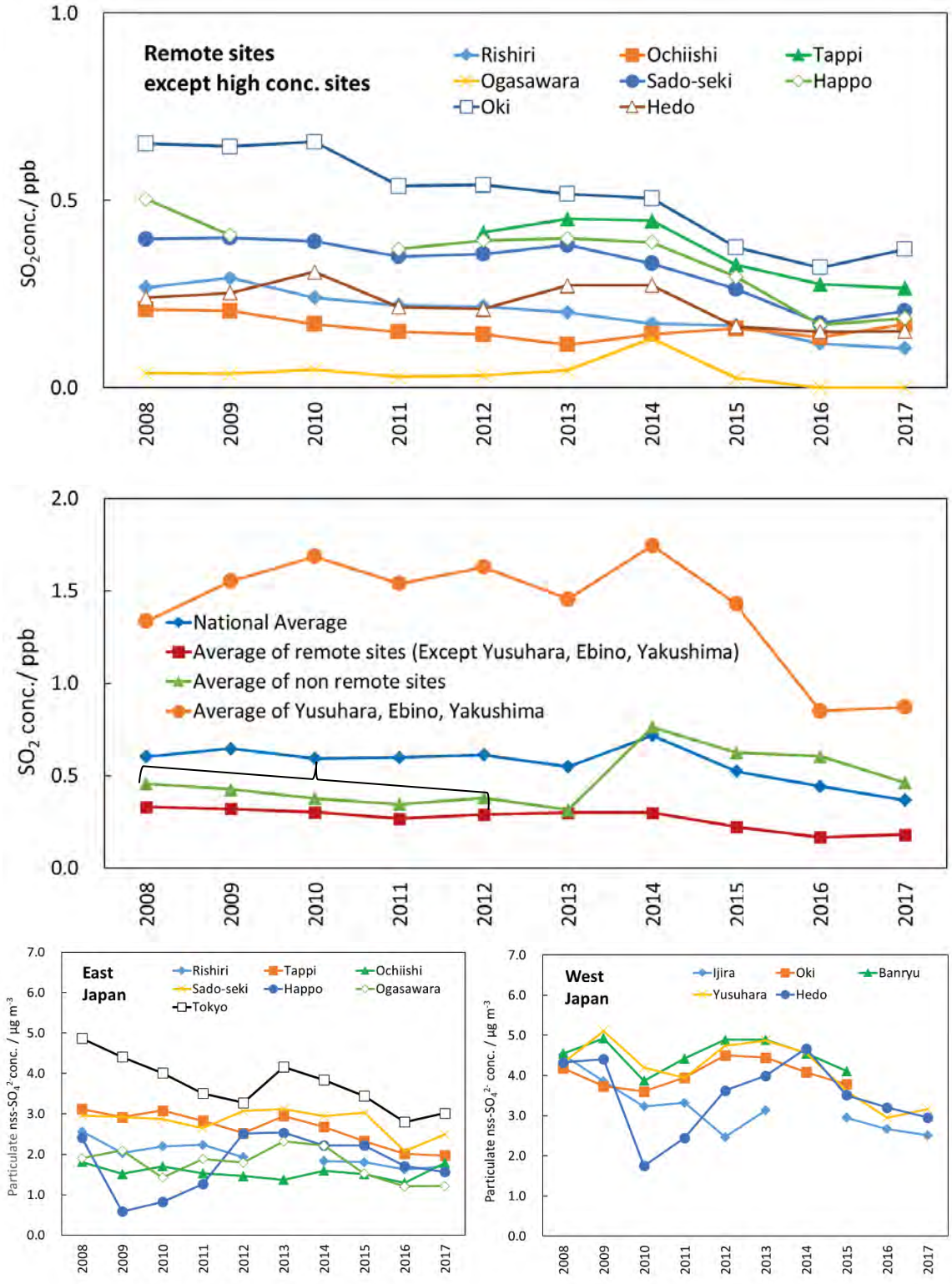


Figure 6. Annual variations of SO_2 (upper and middle panels) and particulate nss-SO_4^{2-} (lower panel) concentrations from FY2008 to FY2017.

Annual values with less than 70% completeness are not shown in the graphs. Their SO_2 annual averages of non-remote sites include only the data of Ijira and Banryu until FY2013, and then have included those of Niigata-Maki, and Sapporo, Nonodake, and Amagasaki since FY2014.

2.2 State of inland aquatic environment

2.2.1 Indication of recovery from acidification

Their concentration levels of sulfate ions and nitrate ions are realized declining in almost all the monitoring lakes.

- According to the analysis results after FY2006, a tendency to recover from acidification was confirmed, such as the disappearance of sites showing a significant decrease in pH. Although their annual variation of alkalinity and cation concentrations vary depending on the sites, the sulfate and nitrate ion concentrations tended to decrease in the most monitoring lakes (Table 3).

- In the previous report (FY2008-FY2012), it was suggested that the pH and alkalinity of Yashaga-ike Lake decreased significantly from FY2000 to FY2012, and that their acidification was progressing, however, in the evaluation from FY2006 to FY2017, there was no significant decrease in pH and alkalinity of Yashaga-ike Lake, and the sulfate ion concentration also decreased. It is considered to be a sign of recovery from acidification of inland water due to the decrease in atmospheric deposition, which reflects the recent downward trend in the emission of acidic substances in East Asia.

- The quality of inland water reflects the results of atmospheric deposition and material cycles within forest ecosystems. Therefore, it is necessary to continue monitoring in order to understand how Japan's forest ecosystem responds and recovers under the ever-changing atmospheric environment in East Asia.

Table 3 Variation of water quality at inland water monitoring sites

Lake (River) name	Start year (FY)	n	Z-score[5]										
			pH	EC	Alkali-nity	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}
Imagami-oike Lake	2001	66	1.46	0.02	0.64	-0.11	-0.07	0.60	0.83	1.99	2.90	2.27	3.48
	2006	48	1.61	-0.24	-0.17	-2.57	-0.66	0.24	-1.27	-1.03	1.82	3.60	3.16
Karikomi Lake	2003	60	1.66	3.19	5.07	1.81	-3.06	2.23	-0.11	3.39	4.61	3.81	4.24
	2006	48	2.09	2.26	3.67	3.12	-3.86	2.40	-1.07	3.81	4.40	3.33	3.44
Ohata Lake	2003	59	4.23	2.53	2.74	-3.98	-0.08	-2.08	-0.11	0.30	4.23	1.57	1.87
	2006	47	2.75	0.21	2.75	-5.01	-2.31	-1.98	-0.60	0.32	3.11	1.80	0.21
Yashaga-ike Lake	2000	69	-2.34	-2.88	-2.97	-3.85	1.55	-3.24	-2.27	-3.10	-2.99	-5.57	-4.61
	2006	46	0.69	-1.82	0.81	-2.95	1.64	-1.13	-0.98	-1.13	-3.14	-4.70	-3.01
Futago-ike Lake (Oike)	1998	60	2.60	2.66	5.44	0.54	-3.07	-3.66	-1.66	4.94	0.45	3.10	1.49
	2006	35	0.21	2.27	5.47	-6.54	-5.93	-1.48	0.14	1.96	-0.16	0.51	-2.01
Futago-ike Lake (Meike)	1998	60	0.75	-5.26	-0.77	-2.77	-5.80	-3.58	-3.13	0.38	-3.57	-4.94	-6.30
	2006	35	1.03	-5.84	-0.05	-7.33	-5.65	-2.90	0.07	-3.93	-4.20	-6.99	-7.07
Ijira Lake	1989	112	-0.61	1.09	4.89	-0.99	0.30	-4.71	-4.15	-3.11	-5.38	-1.07	-2.27
	2006	44	0.69	-3.79	-3.22	-1.15	-2.83	-4.98	-2.97	-3.22	-2.49	-4.36	-3.18
Kamagata-ni River	1989	116	-2.23	-0.64	2.13	-1.78	0.10	-4.01	-4.21	-2.16	-3.80	-3.37	-3.46
	2006	48	0.93	-3.74	-2.09	-2.16	-5.79	-5.69	1.12	-4.08	-1.96	-3.67	-3.74
Kobora River	1989	92	4.62	2.14	2.93	2.22	-0.69	-4.41	-4.35	-0.34	-0.58	-2.61	-1.79
	2006	41	4.07	-2.02	-0.55	-0.76	-3.40	-4.87	-[6]	-2.48	0.17	-2.81	-2.31
Sawano-ike Lake	2003	60	3.34	-3.76	2.97	-2.82	-0.50	-4.92	1.91	1.71	-0.30	-1.76	0.00
	2006	48	2.57	-3.16	1.47	-3.02	1.41	-4.77	1.63	1.47	-1.85	-5.38	-1.06
Banryu Lake	1989	116	1.22	5.43	5.30	-2.60	-1.53	6.87	3.91	6.43	0.61	3.58	6.32
	2006	48	-1.47	-1.72	-1.37	-1.99	-2.94	0.75	0.46	-1.20	-2.78	1.54	0.62

$p<0.05$	-	+
$p<0.01$	-	+
$p<0.001$	-	+

2.3 State of soil and vegetation

2.3.1 Long-term changes in chemical characteristics of soil in forest ecosystems

Significant increase or decrease in soil pH was not suggested from long-term soil monitoring which has been conducted 5-year cycle by site.

- Soil pH (H_2O) in the most of the sites distributed from 4.0 to 5.5. Tendency of increasing or decreasing in soil pH (H_2O) has not been observed at almost all sites.

- Although significant soil acidification was not suggested at the present moment, continuous soil monitoring is needed to understand the long-term changes in soil chemical properties.

[5] Statistic showing the degree of monotonous rising or falling trend. A positive value indicates an upward trend, a negative value indicates a downward trend, and the farther away from 0, the more monotonously the tendency is to rise or fall.
[6] Less than the quantification limit.

2.3.2 Current status of forest ecosystems

Tree decline was not observed at almost all sites. Forest decline caused from artificial factors, such as air pollution, has not been observed, while natural phenomena such as meteorological and pest damage were observed at some sites.

- Soil and vegetation monitoring has been conducted on a rolling system once every five years in a total of 19 regions (25 sites) targeting forest area; i.e., 13 regions focusing on tree impacts and 6 regions focusing on soil impacts.

- The total breast-height cross-sectional area estimated from tree census tended on the increase except some of their monitoring site. Tree decline was not suggested regarding the viewpoint of tree growth.

- In the tree decline index, the decline degrees were high at Daisen-Oki, Towada-Hachimantai, Yoshino-Kumano and Bandai-Asahi, and their degrees at some sites were observed continuous rise. The causes of decline in these sites were suggested as natural phenomena, such as meteorological, pest and animal damage, and forest decline attributed to artificial factors such as air pollution has not been confirmed.

- The survey sites for soil and vegetation monitoring include many national and quasi-national park areas, existing natural forests in the late succession period. The monitoring data obtained through this program are valuable to grasp the current status of natural forests in Japan and to promote protection and conservation of their natural environment.

- Effects of air pollution and acid deposition on forest ecosystem have not been sufficiently elucidated at this moment yet. Soil and vegetation monitoring is needed in order to continuously understand how Japan's forest ecosystem responds to the changing atmospheric environment of East Asia.

2.4 State of catchment-scale monitoring

2.4.1 Lake Ijira catchment-scale monitoring

In the Lake Ijira catchment (Gifu Prefecture), where the effects of acid deposition have been continuously monitored, the decrease of dissolved inorganic nitrogen concentration and the upward trend of precipitation pH and river pH were observed, suggesting recovery from nitrogen saturation and acidification.

- In the Ijira Lake catchment area, the inflow of sulfur and nitrogen derived from precipitation tended to decrease. The outflow also tended to decrease in response to the concentration of dissolved inorganic nitrogen particularly. Precipitation concentrations and river water concentrations also tended to be the same (Figure 7). The annual weighted average of river pH also rose from 6.8 to 7.0 from FY2006 to FY2017 and returned to the levels in the early 1990s, suggesting that the Lake Ijira catchment is recovering from nitrogen saturation and acidification

due to a decrease of pollution inflow from the atmosphere.

- It is necessary to continue the current monitoring in order to grasp the trend of nitrogen saturation and acidification in the Lake Ijira catchment.

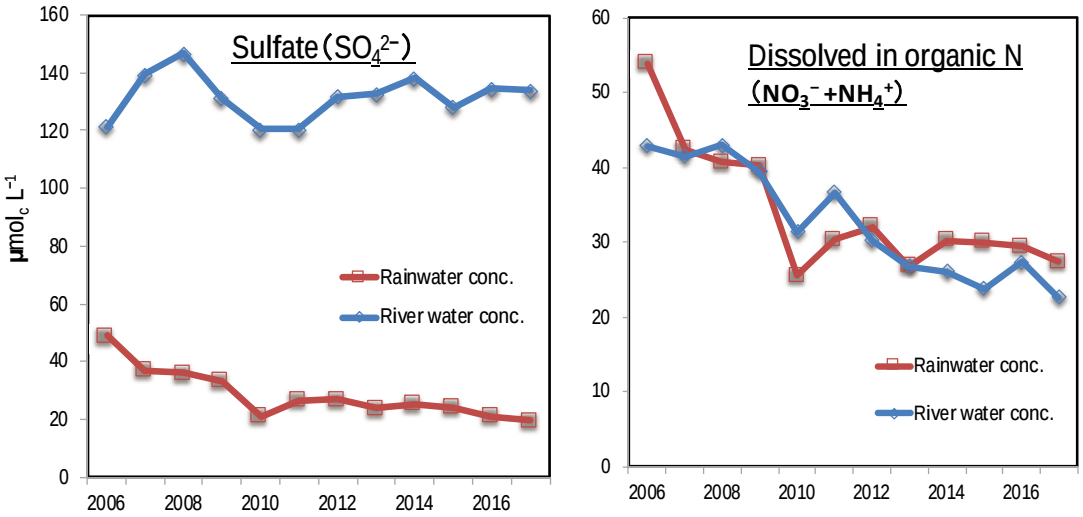


Figure 7. Changes in annual weighted average concentrations of sulfate (SO_4^{2-}) and dissolved inorganic nitrogen (N) in the Lake Ijira catchment.

2.5 Others

2.5.1 Possibility of ozone effects on plants

Investigations of ozone concentrations during plant growth periods in forest and mountainous areas, which had not been clarified enough before, suggested that the current ozone concentrations at Mt. Hakkai-san and Mt. Hiko-san were levels that might cause tree growth decline.

- In mountainous areas, the diurnal variations were not very large compared to urban areas. Therefore, once it becomes high concentration, there is a concern that the effect on plants will become more pronounced by increase in exposure time and exposure amount.

- At present, the effects of ozone on trees have not been confirmed in Mt. Hakkai-san (Niigata Prefecture) and Mt. Hiko-san (Fukuoka Prefecture). On the other hand, the AOT40[7], which is an index of influence on tree growth, was levels (8 – 15 ppm·h) that cause decrease in beech growth by 10% in the single growth period (6 months), according to exposure experiment data for about 2 years using seedlings so far.

[7] AOT40 (Accumulated exposure Over a Threshold of 40 ppb): An integrated value of ozone concentration exceeding 40 ppb. In this report, AOT40 is accumulated all values of which 1-hour value was over 40 ppb from 6:00 to 18:00, depending on the growth period of the tree from May to October.

- It is necessary to monitor ozone concentrations and observe the status of trees in these regions in the future.

Table 4 Ozone concentrations and the effect indices during the tree growing season (May – October) at Mt. Lake Mashu, Mt. Hakkai-san, and Mt. Hiko-san

Mt. Lake Mashu	Unit/yr	2013	2014	2015*1	2016*2	2017*3
95 percentile value	ppb	40	35	32	30	54
Median	ppb	22	20	20	18	30
5 percentile value	ppb	9.3	11	10	7.7	14
AOT40	ppm·h	0.39	0.23	0.01	-	2.4

Mt. Hakkai-san	Unit/yr	2013*4	2014	2015	2016	2017*5
95 percentile value	ppb	52	78	77	69	80
Median	ppb	35	46	46	43	47
5 percentile value	ppb	12	27	25	24	26
AOT40	ppm·h	2.3	19.5	19.4	13.8	15.9

Mt. Hiko-san	Unit/yr	2013	2014	2015	2016*6	2017*6
95 percentile value	ppb	73	72	69	69	74
Median	ppb	42	41	42	38	40
5 percentile value	ppb	17.5	13	13	13	15
AOT40	ppm·h	16.8	15.7	15.4	11.8	15.4

*1. Observation: June - October; *2. Observation: July - October; *3. Observation: May - August; *4. Observation: From the late May; *5. Observation: May - September; *6. Missing data in early May.

2.5.2 Substances derived from air pollution flowing into ecosystems

The results of sulfur isotopic-ratio analysis suggest that sulfur oxides from the continent are also transported to Japan due to the northwesterly seasonal winds in winter. It was also suggested that the Pacific side has been influenced by transboundary air pollution in addition to domestic pollution sources, although the effect was more pronounced on the Sea of Japan side.

- The Lake Ijira catchment located inland on the Pacific side has been largely influenced by domestic pollution sources derived from the Chukyo Industrial Area, and it has been known that the amount of sulfate ion (SO_4^{2-}) deposited by precipitation is large in summer (July – September). However, the isotopic ratio of non-sea salt sulfur (nss-S) in precipitation rose in winter as well as the Kajikawa catchment on the Sea of Japan side (Figure 8), and it was suggested that sulfur oxides have been transported to Japan due to northwesterly seasonal winds blowing from the continent in addition to those from domestic pollution sources.

- The hydrogen and oxygen isotopic ratios (d-excess value[8]) in precipitation showed a clear seasonality that increased in winter as well in the Lake Ijira catchment and the Kajikawa catchment (Figure 9). This is because isotopic fractionations occur when water vapor is rapidly

[8] d-excess value: An index value calculated from the isotope ratio of hydrogen and oxygen, which reflects the origin of water vapor. The value is calculated by the equation; d-excess value = $\delta^2H - 8 \times \delta^{18}O$

supplied from the Sea of Japan to the cold and dry atmosphere blowing out of the continent in winter. It was suggested that the Lake Ijira catchment was also influenced by air masses transported from the continent through the Sea of Japan in winter.

- Both results suggest that not only the Kajikawa catchment on the Sea of Japan side but also the Lake Ijira catchment on the Pacific side is influenced by transboundary air pollution.

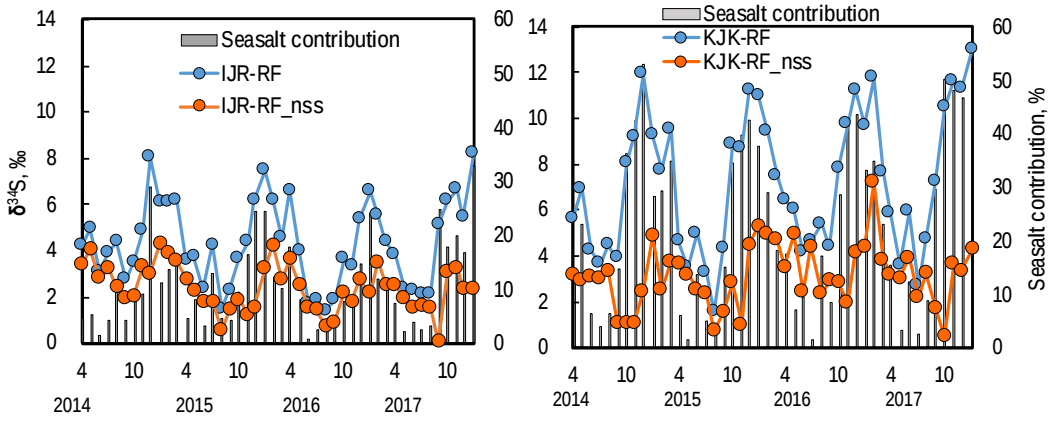


Figure 8. Sulfur isotopic ratio ($\delta^{34}S$) of rainwater collected at Lake Ijira catchment (left) and Kajikawa catchment (right).

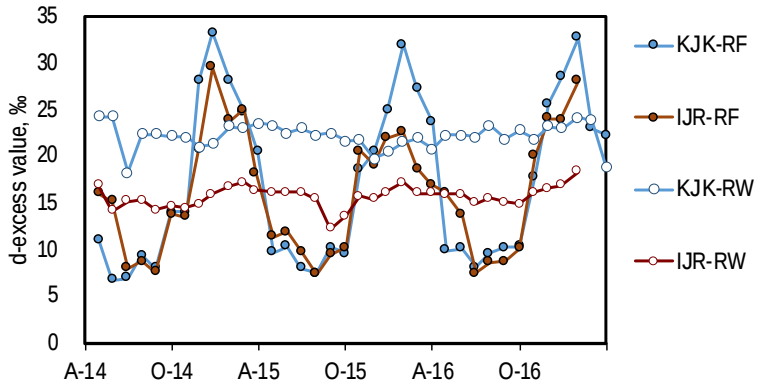


Figure 9. Oxygen and hydrogen isotopic ratios of rainwater (RF) and river water (RW) at Lake Ijira catchment (IJR) and Kajikawa catchment from May 2014 to April 2017 (KJK) (d-excess value : $\delta^{2}H - 8 \times \delta^{18}O$).

2.5.3 Dynamics of atmospheric substances in forest catchments

The isotopic analysis suggests that sulfur derived from precipitation is retained and circulated in ecosystems due to adsorption in soil and absorption by plants, and then flowed out into rivers.

- While the sulfur isotopic ratio in precipitation showed a clear seasonality, those in soil solution and river water remained stable throughout the year (Figure 10). Since the annual weighted average value of the sulfur isotopic ratio in precipitation is close to that in river water, it was suggested that sulfur derived from the atmosphere in precipitation does not flow into the river directly, but is retained, circulated, and homogenized in the ecosystem due to adsorption in the

soil and absorption by plants, and then flowed out of the river.

- The hydrogen and oxygen isotopic ratios (d-excess value) in river water was almost constant throughout the year unlike that in precipitation (Figure 9). It is suggested that precipitation flowing into forest catchment areas flows into inland water after circulation, retention, and homogenization.

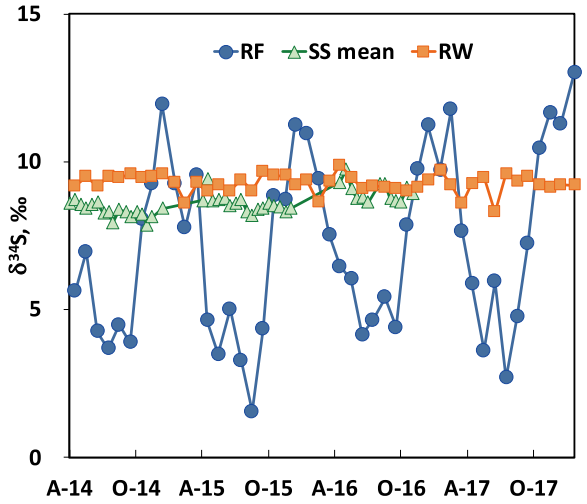


Figure 10. Sulfur isotopic ratios ($\delta^{34}S$) in rain water (RF), soil solution (SS), and river water (RW) at the Kajikawa catchment from May 2014 to February 2018. The value of soil solution is the average of all sampling points.

2.5.4 Long-term trend of ozone concentration

As for ozone, the 3-year moving averages of the annual 99th percentile value of daily maximum 8-hour averages[9], showed the significant decrease at 9 sites of 23 domestic monitoring sites.

- In order to evaluate the long-term trend of ozone concentration, the analysis was performed using the 3-year moving average of the annual 99th percentile at 23 domestic monitoring sites from FY2005 to FY2017.

- The significant decreasing trends ($p < 0.05$) were found in 9 monitoring sites shown in the following; Rishiri (-1.3 ppb y^{-1}), Tappi (-2.4 ppb y^{-1}), Sadoseki (-0.8 ppb y^{-1}), Happo (-2.1 ppb y^{-1}), Hedo (-0.8 ppb y^{-1}), Akagi (-3.1 ppb y^{-1}), Niigata-maki (-1.3 ppb y^{-1}), Ebino (-3.3 ppb y^{-1}), Yakushima (-1.1 ppb y^{-1})

[9] Ozone, which accounts for the majority of photochemical oxidants is measured by automatic monitors. For ozone evaluation, a daily maximum value of 8-hour moving average in a day is calculated, then these values (the total number for a year: 365) are arranged in order from the lowest value to the highest value. Then the 99th percentile value from the lowest is selected as a representative annual value. While the value may reflect high-concentration events, it is not easily affected by weather conditions and year-to-year fluctuations. Additionally, the evaluation index is consistent with research results on the ecological effects of ozone, so is mainly used for evaluation of long-term trends.

- On the other hand, the significant increasing trend ($p < 0.05$) was shown in Tsushima (+1.1 ppb y^{-1}). No significant trend such as increase or decrease was observed at the other 13 sites.

Chapter 3. Conclusion and Promotion of Domestic and International Efforts

3.1 Promotion of domestic efforts

- The impact of acid rain is difficult to assess without analysis of long-term continuous monitoring. Furthermore, if the buffering capacity of lakes and soils is low, the accumulation of acidic substances exceeding a certain load threshold will induce a rapid onset of acidification effects. Therefore, it is essential to continue steadily implementation of long-term monitoring.

- As a public concern about the health effects of $PM_{2.5}$, tropospheric ozone, etc. is high, and the items that should be weighted are changing, it is necessary to carry out long-term continuous monitoring taking into consideration these above issues. In addition, to keep up the technical level of measurement, closer cooperation and collaboration between the local governments involved in the monitoring and the Ministry of the Environment Government of Japan (MOEJ) is important.

- On the other hand, in order to continue to obtain high-quality monitoring data while properly maintaining and managing monitoring sites including their equipment updates with a limited budget, it is necessary to review the monitoring plan, especially for consolidating monitoring sites based on the past monitoring results.

- In order to comprehensively and accurately analyze and evaluate the situation of transboundary air pollution including acid deposition and ozone, it is necessary to further proceed the high quality monitoring based on the improvement of analytical quality by the inter-laboratory comparison projects. To proceed the clarification of ecological impacts by the atmospheric pollution in the prioritizing areas where the acid buffering capacity of soil and geology is small and the amount of acid deposition due to sulfur oxides and nitrogen oxides is high, it is necessary to continue the comprehensive judgement including the impact assessment of atmospheric deposition such as catchment monitoring. Furthermore, in order to clarify the behavior and dynamics of atmospheric-derived materials in ecosystems, isotopic monitoring is carried out as necessary.

- It is necessary to continue pilot monitoring of their plant effects from ozone, to monitor the actual conditions of pollution in mountainous and forest areas where high concentrations of ozone are observed and their symptoms of ozone effects, and to collect information on their actual combined impacts of air pollution and other factors (such as insect damage). In addition, our efforts are needed to elucidate the combined effects of particulate matter and ozone on forest trees.

- For considering control measures for such as reduction of $PM_{2.5}$ emissions and mitigation of photochemical oxidant pollution, the accurate understanding of the current status of air pollution is necessary not only through the analysis and evaluation of long-term monitoring data, but also

by promoting cooperation with emission inventories, numerical models, satellite observations, and other efforts. Long-term monitoring data is also very important as validation data for numerical models that simulate transboundary air pollution. Furthermore, it is expected to contribute greatly to improve the accuracy of models that are also important for future predictions.

3.2 Promotion of international efforts

- In order to grasp the pollution situation of East Asia as a whole, it is necessary to enhance monitoring about today's air pollution such as $PM_{2.5}$, ozone, etc. by sharing the latest scientific knowledge with the participating countries of the Acid Deposition Monitoring Network in East Asia (EANET) through continuous to work without being bound by the conventional narrowly defined acid rain framework.

- It is necessary to utilize Japan's experience and technology to strengthen regional cooperation so that Asian countries can share a clean atmosphere. It is necessary to promote international cooperation that will lead to the mitigation of cross-border air pollution in Japan through cooperation with various organizations such as Japan-China-Korea efforts based on the Japan-China-Korea Trilateral Environment Ministers' Meeting (TEMM), strengthening bilateral cooperation with China and Republic of Korea, and Asia-Pacific Clean Air Partnership (APCAP).

- The 10th International Conference on Acid Rain, a scientific meeting on acid rain and its effects, is scheduled to be held in Niigata City in 2022. It is considered meaningful to hold the meeting, which includes today's air pollution such as $PM_{2.5}$ and ozone and its effects, without being bound by the conventional narrowly defined acid rain framework. Hopefully, the latest scientific knowledge will be shared with Asian countries and that the 20-year achievements of EANET led by Japan will be widely promoted. It is also expected that this will be an opportunity to deepen discussions on the direction of EANET development in the near future.

National Assessment on Acid Deposition in Lao PDR

by

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1. Basic Information on National Monitoring Activities

1.1. Outline of the activities on acid deposition and national monitoring plan

Lao People's Democratic Republic (Lao PDR) is a landlocked country surrounded by Myanmar, Cambodia, China, Thailand and Viet Nam. The total land area of the country is 236,800 km^2 with a largely mountainous topography. Vientiane is the capital city, however lies on a plain. The country is bordered on the West by the Mekong River, making the river an important artery for transportation, communication and trade with other countries sharing tributaries of Mekong River.

The country has a tropical monsoon climate, characterized mainly by a rainy season (May to October) and dry season (November to April) and temperatures ranging from 5ºC to 40ºC depending on altitude. Humidity is generally high in the 70% to 80% range.

Acid Deposition issues are a fairly new phenomenon for Lao PDR and the interest in the prevention of this problem is still gaining momentum. There is lack of knowledge on various aspects of sulfur and nitrogen pollution including emissions, atmospheric transport and deposition, direct impacts of gases on human health, vegetation and corrosion of monuments and indirect impacts via changes in the soil.

Realizing the need to protect the country from the acid deposition problem, Lao PDR became one of the participating countries of EANET in November 2002. Since then, in order to ensure the monitoring activities of acid deposition in Lao PDR, the country has nominated the National Center for developed and implementing the nation monitoring plan as well as collecting the national monitoring data, promoting national QA/QC activities, public awareness raising through the acid deposition brochure and dealing with technical matters on the network activities in the country.

The national monitoring activities on acid deposition monitoring was established and started monitoring wet deposition in Vientiane capital city by collecting daily sample (during rainy season) and established the dry deposition monitoring at the same site of wet deposition monitoring. The activities also were surveyed the appropriate monitoring site for inland aquatic at the Nam Hum lake and collected samples and analysis for observed data.

All activities were carried out by to Environment Quality Monitoring and Hazardous Chemical Center (EQMHCC), the National Center under Water Resources and Environment Research Institute (WERI) of Water Resources and Environment Administration (WREA) until 2011 was changed its name Environment Quality Monitoring Center (EQMC), under Natural Resources and Environment Research Institute (NRERI), Ministry of Natural Resources and Environment (MONRE).

1.2. Monitoring program from 2002-2019

The national monitoring plan covers the generation of the relevant data and activities, operation and maintenance of field and laboratory facilities and conduct of QA/QC activities.

- For wet deposition monitoring to collecting daily sample and analyzed was conducted at the Department of Meteorological and hydrological stations. Ministry of Natural Resources and Environment (MONRE). Measurement parameters: Precipitation amount, pH and Electric Conductivity (EC). Anion: SO_4^{2-}, NO_3^-, Cl^- and Cation: Na^+, NH_4^+, K^+, Ca^{2+}, Mg^{2+} by using Ion Chromatography.

- For dry deposition monitoring, surveyed and established monitoring site at the Department of Meteorological and hydrological, Ministry of Natural Resources and Environment (MONRE) in Vientiane (2009) and start to collecting weekly sample in 2010. Measurements were done 12 parameters as follows: SO_2, HNO_3, HCl, NH_3, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} by using the Ion Chromatography.

- For ambient air quality monitoring established monitoring site at the Department of Meteorological and Hydrological, Ministry of Natural Resources and Environment (MONRE) in Vientiane Capital (2013) and start to analyses by using the automated. Measurements were done 3 parameters: NO_x, PM_{10} and $PM_{2.5}$.

- For ambient air quality monitoring mobile unit established monitoring at prime minister ‘office (PMO) and Ministry of Natural Resources and Environment (MONRE) in (2014). Measurement parameters: NO, NO_2, NO_x, PM_{10}, SO_2, O_3, CO and VOCs.

- For inland aquatic monitoring to survey monitoring site at Nam Hum Lake and collected sample and analyses follow the EANET manual parameters: pH, EC, Alkalinity. Anion: SO_4^{2-}, NO_3^-, Cl^-, PO_4^{3-} and cation: Na^+, NH_4^+, K^+, Ca^{2+}, Mg^{2+}, by using IC.

- For raising awareness and training on acid deposition to conducted national awareness workshop on acid deposition for relevant ministries and for the primary school teacher and student from National University of Laos (NUOL) especially Faculty of Science and Faculty of Environmental Science.

- To participant the activities analysis samples of Inter-laboratory comparison project on acid deposition: Wet and Dry deposition samples and Inland water.

1.3. Monitoring stations

The acid deposition station in Lao PDR

Table 1.1 Acid deposition monitoring sites in Lao PDR

Site category	Site classification	Location
Acid deposition monitoring Site: Wet deposition	Urban	Environmental Laboratory of Ministry of Natural Resources and Environment (MONRE)
Acid deposition monitoring Site: Dry deposition	Urban	The same as the wet deposition monitoring site
Ambient Air Quality Monitoring Station	Urban	Vientiane capital (Department of Meteorological and hydrological, Ministry of Natural Resources and Environment (MONRE)
Ambient Air Quality Monitoring Site: Mobile Unit	Urban	Environmental Laboratory of Ministry of Natural Resources and Environment (MONRE)
Ecological survey site: Inland aquatic monitoring	Rural	Nam Hum lake Vientiane capital
Ecological survey site: Soil and Vegetation monitoring	not start yet	

1.4. Sampling and measurements

Rainwater samples for wet deposition monitoring were collected by the “Wet only sampler” installed on site. Gas and aerosol samples for dry deposition monitoring were collected by filler pack. Lake water samples were collected directly to the sample containers. The analytical methods were following by the EANET manuals. For the ambient air quality monitoring, mobile unit and station performs its real-time measurement.

Figure 1.1. Monitoring station for wet and dry deposition.

Figure 1.2. Ambient Air Quality Monitoring Mobile Unit.

Figure 1.3. Ambient Air Quality Monitoring Station.

2. State of Acid Deposition in Lao PDR

2.1 Atmospheric deposition

The global climate is changing. All witness changes are in average temperatures, shifts in seasons and an increasing intensity of extreme weather events. In Lao PDR, the effects of climate change are already visible and will become more evident in the future. Currently accurate predictions of the potential changes in climatic conditions and resulting adverse impact of such changes have not been developed nationally by the Lao PDR but some indication can be taken from preliminary regional level predictions.

2.1.1. State of wet deposition

For the period 2002-2019, wet deposition samples were collected in the Vientiane monitoring station and analyzed for pH, Electrical conductivity, Anion and Cation concentrations (Table 2.1).

Table 2.1 Annual rainfall amount, pH and EC in Vientiane

Station	Year	Rainfall (mm y^{-1})	pH	EC (mS m^{-1})
Vientiane capital monitoring site	2002			
	2003	(88.6)	(6.51)	2.07
	2004	442	(5.65)	2.65
	2005	665	6.32	1.01
	2006	709	6.49	0.764
	2007	1399	5.67	0.396
	2008	1668	6.01	0.644
	2009	(181)	(5.48)	(0.534)
	2010	***	***	***
	2011	***	***	***
	2012	(1322)	(6.46)	(0.411)
	2013	***	***	***
	2014	1273	6.54	0.867
	2015	921	5.94	1.26
	2016	713	(6.77)	(0.730)
	2017	1337	*	*
	2018	829	*	*
	2019	700	*	*

***: No data or no measurement, *: The constituent was rejected or not measured although precipitation was not 0 mm., (): %PCL≤80% and/or %TP≤80%

The annual mean pH values were of the range 5.67 – 6.54 (6 years observation). The mean pH values were 6.16 ± 0.34. The highest annual average precipitation pH was observed in 2007 and the lowest was observed in 2014. There was no clear trend in the time series (Table 2.1. and Figure 2.1.).

The electrical conductivity values were of the range 0.396 – 2.65 $mS.m^{-1}$. The overall mean electrical conductivity was 1.21 ± 0.77 $mS.m^{-1}$. The highest annual average precipitation EC was observed in 2004 and the lowest was observed in 2007. There was no clear trend in the time series (Table 2.1 and Figure 2.1.).

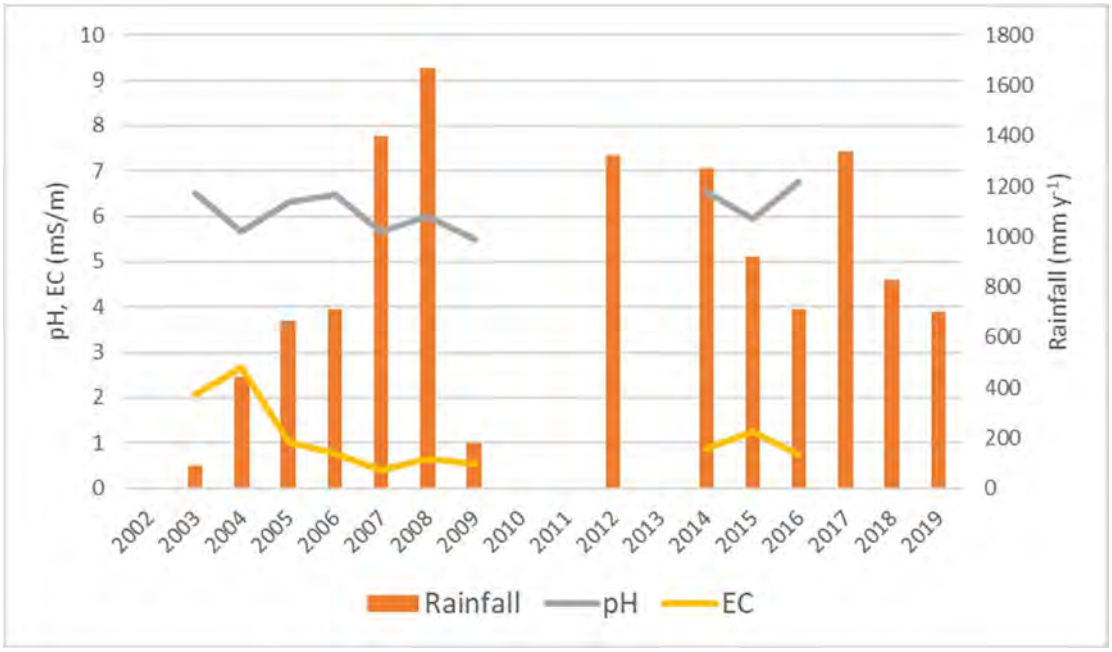

Figure 2.1. Annual variation of rainfall amount, pH and EC in Vientiane.

For Anions and Cations in the period of 2002-2019, rainfall samples were collected in Vientiane monitoring station and analyzed for Sulfate (SO_4^{2-}), Nitrate (NO_3^-), Chloride (Cl^-), Ammonium (NH_4^+), Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) concentrations by using Ion Chromatography (Table 2.2 and Figure 2.2.).

Table 2.2 The annual mean concentrations of anion and cation in Vientiane

Year	SO_4^{2-} µmol.L^{-1}	NO_3^- µmol.L^{-1}	Cl^- µmol.L^{-1}	NH_4^+ µmol.L^{-1}	Na^+ µmol.L^{-1}	K^+ µmol.L^{-1}	Ca^{2+} µmol.L^{-1}	Mg^{2+} µmol.L^{-1}
2002								
2003	***	***	***	***	***	***	***	***
2004	***	***	***	***	***	***	***	***
2005	***	***	***	***	***	***	***	***
2006	(3.46)	(6.94)	(4.77)	(7.72)	(7.10)	(3.51)	(8.75)	(3.49)
2007	4.67	6.90	7.42	10.9	2.38	1.69	3.04	0.70
2008	5.06	5.96	7.41	8.39	2.91	1.69	5.77	1.31
2009	(4.05)	(9.73)	(6.19)	(17.3)	(9.14)	(0.93)	(5.50)	(0.72)
2010	***	***	***	***	***	***	***	***
2011	***	***	***	***	***	***	***	***
2012	(2.41)	(5.55)	(4.46)	***	***	***	***	***

2013	***	***	***	***	***	***	***	***
2014	***	***	***	***	***	***	***	***
2015	3.19	4.12	4.97	7.78	2.78	1.74	4.00	0.61
2016	(3.66)	(4.07)	(5.28)	(7.50)	(1.52)	(0.96)	(2.21)	(<0.3)
2017	*	*	*	*	*	*	*	*
2018	*	*	*	*	*	*	*	*
2019	*	*	*	*	*	*	*	*

***: No data or no measurement, *: The constituent was rejected or not measured although precipitation was not 0 mm., (): %PCL≤80% and/or %TP≤80%

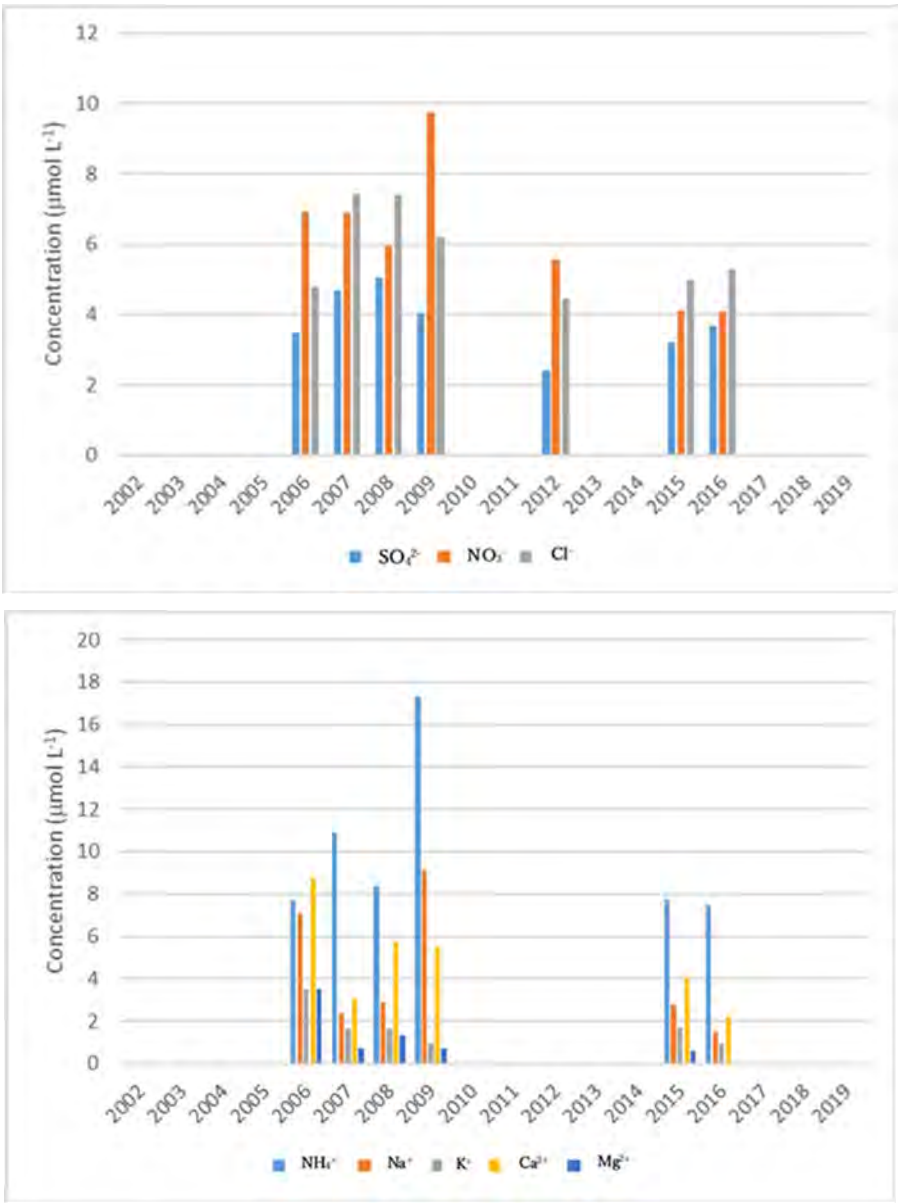

Figure 2.2. The values of sulfate, nitrate and chloride, ammonium, sodium, potassium, calcium and magnesium concentration.

Precipitation acidity is ususally evaluated by the concentration diffrences between sum of non-seaslt anions (nss-SO_4^{2-}+NO_3^-) and sum of non-seasalt cations (nss-Ca^{2+}+NH_4^+) dissolved in rainwater. In the case in Vientian, as the result calculated by using high quality data only, sum of non-seasalt cation concentration were usually higher than that of anion concentration. Therefore, it was considered that

environmental acidification by precipitation was not significant at least in the monitoring period (Table 2.2 and Figure 2.2.).

2.1.2. State of dry deposition

Lao PDR established the dry-deposition monitoring station in Vientiane (same as the wet deposition monitoring site) at the end of 2009 and started collecting sample and analyses in 2010. But the results not available because it has some problem about the Instrument Ion Chromatography System since 2010-2014. After repair the IC system, concentrations of gas and particle have been monitored successfully as shown below (Table 2.3).

Table 2.3 The mean concentrations of Gas and Particle for 2016 in Vientiane capital city monitoring station

	Gas (ppb)				Particle (μg m^{-3})							
	SO_2	HNO_3	HCl	NH_3	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
Jan	0.5	<0.1	0.4	3.2	5.73	0.38	0.02	1.57	0.31	0.83	0.06	0.31
Feb	0.6	0.3	0.3	3.7	5.20	0.65	0.03	1.58	0.22	0.78	0.08	0.23
Mar	0.5	0.6	0.4	3.8	6.30	0.51	0.05	1.90	0.51	0.70	0.09	0.28
Apr	0.4	0.4	0.4	3.3	3.85	0.12	0.06	1.21	0.17	0.40	0.03	0.14
May	0.4	0.2	0.3	2.3	3.19	0.83	0.07	0.77	0.27	0.16	0.06	0.18
Jun	0.6	0.1	0.2	2.6	1.06	0.47	0.18	0.29	0.21	0.11	0.03	0.28
Jul	0.2	0.2	0.1	1.8	1.90	0.58	0.07	0.58	0.25	0.08	0.05	0.31
Aug	0.2	0.1	0.1	2.0	1.92	0.43	0.08	0.55	0.24	0.10	0.04	0.22
Sep	0.3	0.2	0.1	1.9	1.05	0.27	0.07	0.38	0.10	0.16	0.02	0.10
Oct	0.2	0.1	0.2	2.1	3.42	0.11	0.01	1.18	0.22	0.18	0.03	0.13
Nov	0.5	0.3	0.3	2.9	4.50	0.28	0.02	1.42	0.27	0.43	0.04	0.15
Dec	0.2	0.2	0.2	2.6	7.13	0.22	0.03	1.99	0.24	0.33	0.05	0.31
Annual	0.4	0.2	0.2	2.7	3.77	0.40	0.06	1.12	0.25	0.36	0.05	0.22

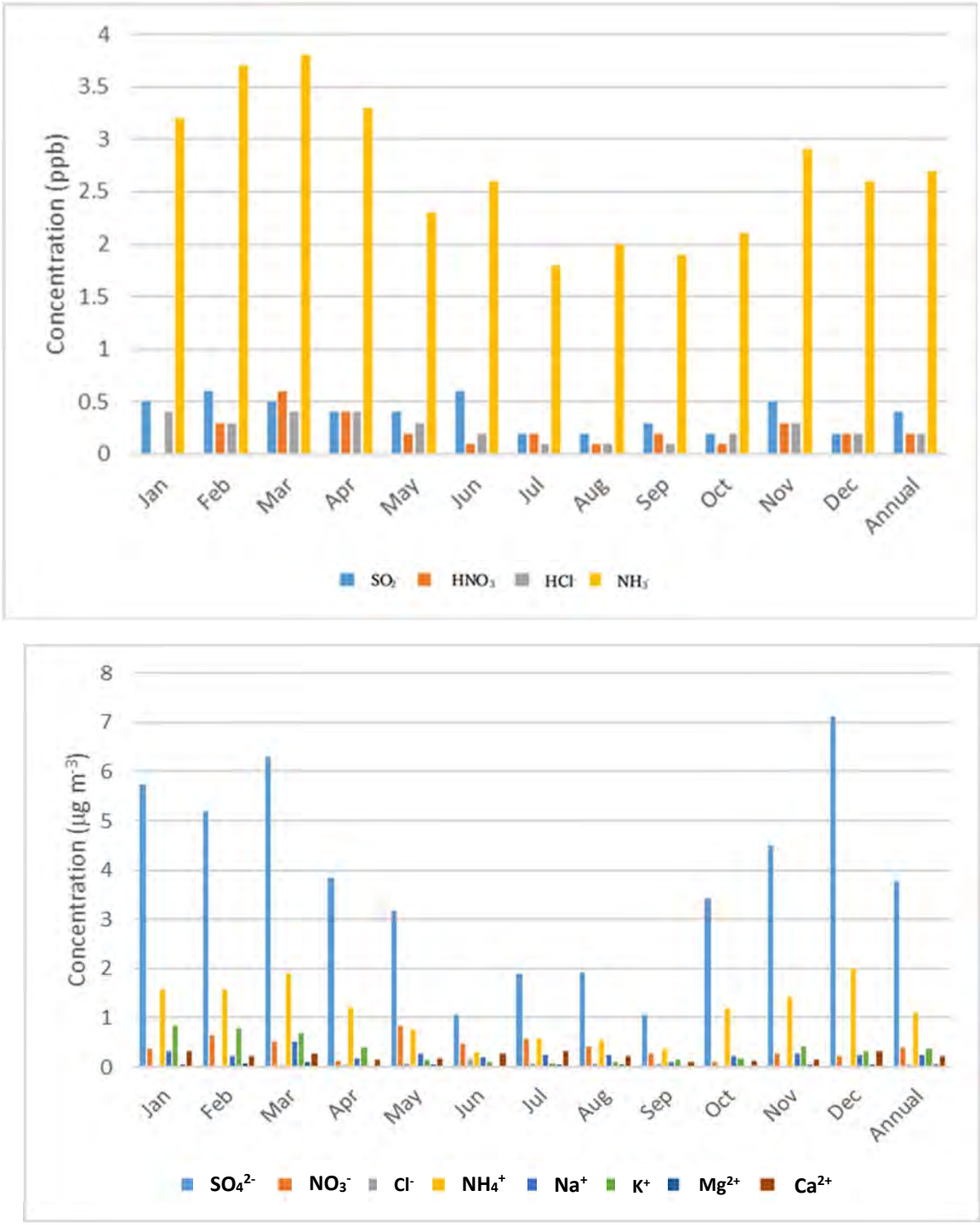

Figure 2.3. Seasonal variation of gas (ppb) and aerosol component (µg m^{-3}) concentration in Vientiane in 2016.

As for gaseous components, NH_3 concentration is extremely higher than the other gas components. Sulfur dioxides are next higher gas components even though the concentration is quite low comparing with NH_3. In the aerosol components, sulfate concentration was the highest and ammonium ion followed. From the ratio between sulfate and ammonium ion concentrations, ammonium sulfate was considered as major component in the aerosol (Figure 2.3.).

The $PM_{2.5}$ concentration monitoring has been started in 2018 in Vientian. Annual mean concentration in 2019 was 32 mg m^{-3} in Vientiane with seasonal variation in which high and low concentrations were observed from the end of year to March and in summertime (from June to August), respectively (Table 2.4).

Table 2.4 Seasonal variation of $PM_{2.5}$ concentration in Vientian (μg m^{-3})

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2018											30	32	31
2019	44	55	80	44	22	13	12	9	23	25	30	44	32

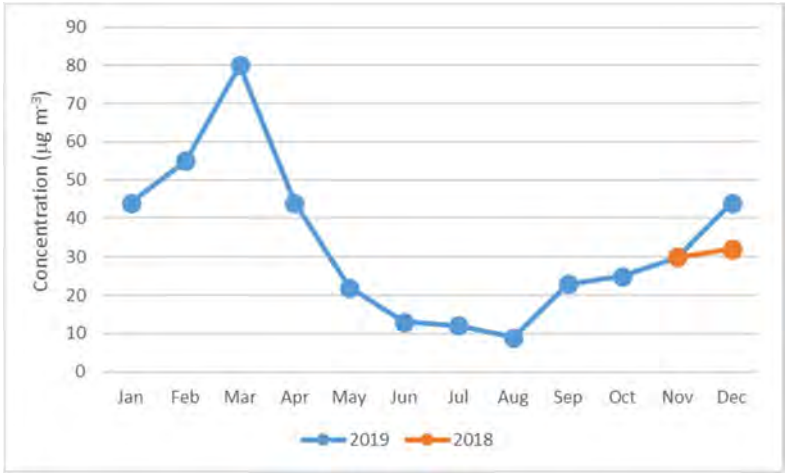

Figure 2.4. Annual variation of $PM_{2.5}$ concentration in Vientian.

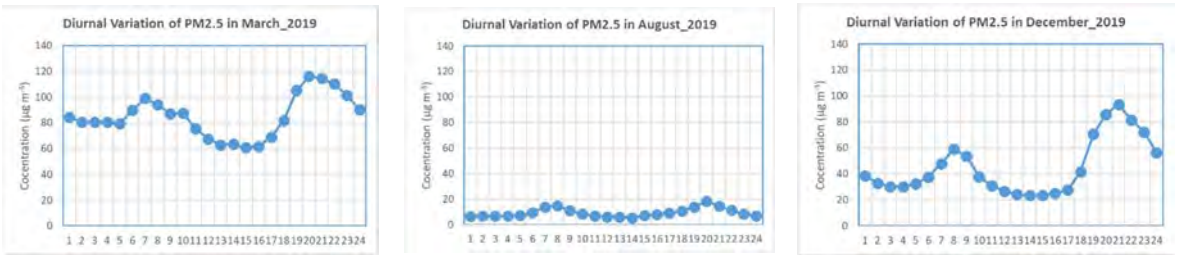

Figure 2.5. Diurnal variation of $PM_{2.5}$ in March, August and December, 2019.

Diurnal variations of $PM_{2.5}$ concentration in Vientiane were shown for March, August, and December to identify the sources of $PM_{2.5}$. $PM_{2.5}$ cocentration has two peaks in early moning and late evening, regardless of whether the monthly average concentration is high or low. Condisering the site location and seasonal variation of peak hight into account, those variations of $PM_{2.5}$ concentration might be affected by the automotive exhaust gas and inversion layer in urban area (Figure 2.4. and 2.5.).

2.2. State of inland aquatic environment

For inland aquatic in Lao PDR were surveyed for candidate sites in Vientiane in 2005 at Nam Hum lake and collected sample and analyzed at the end of 2009 for observed data to consider Nam Hum lake as the monitoring site for inland aquatic environment. In 2010 Lao PDR started to collect sample

and analyzed the parameters as the EANET manual, but the result was not available because the quality of deionized water and it has some problem about the Instrument Ion Chromatography System Since 2010-2013.

After repair the instruments, the monitoring was restarted. The latest monitoring results were obtained and summarized in the following table (Table 2.5).

Table 2.5 Result of four season inland aquatic environment monitoring in 2019 in Nam Hum Lake

Date	Temp (°C)	pH	EC (mS/m)	Alk (meq/L)	Trans-parency (m)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	Cl^- (mg/L)	PO_4^{-3} (mg/L)	DO (mg/L)	COD (mg/L)
3/13	26.1	7.95	3.30	0.30	0.5	3.34	0.01	0.48	0.01	8.6	29.9
6/13	26.3	8.08	3.41	0.40	0.5	3.72	0.01	0.25	0.01	8.9	15.7
9/13	29.8	8.15	3.39	0.31	0.5	3.90	0.01	0.48	0.01	8.6	12.5
12/13	31.4	8.06	3.37	0.34	1.0	3.65	0.01	0.40	0.01	8.7	19.3
Mean	28.4	8.05	3.37	0.34	0.6	3.65	0.01	0.40	0.01	8.7	19.4

Figure 2.6. View of Nam Hum Lake monitoring site.

2.3. State of soil and vegetation

Lao PDR has not yet decided for soil and vegetation monitoring activities at this time due to constraints for instruments and capacity building. However, the national center will consider conducting soil and vegetation monitoring in the future.

3. Air Quality Management

3.1. Legislation and Mandate

There is no specific air pollution control act or law that provides a legal framework for air quality management in the country. Article 27 of the Lao PDR's Constitution (2013) has a provision for Lao National Environmental Standard as the basis for the environmental monitoring and pollution control on water, soil, air and noise. "all organizations and citizens must protect the environment and the natural resources: land, underground, forests, fauna, water sources and the atmosphere"

In addition to the Constitution, the Environmental Protection Law (EPL) 2013 is the main environmental legislation relevant to Lao PDR at the national level. The EPL mandates the Ministry of Natural Resources and Environment (MONRE) responsible for environmental protection. Nevertheless, MONRE and MPWT still have the decree and implemented some programs below to protect environment:

- Decree on the National Environmental Standard No. 2734/PMO.WREA dated 7 December 2009
- Decree on The Vehicles Technical Standard and Vehicles Accessory, Permit, import to register in Lao PDR No. 4312/MPWT dated 11 November 2002
- Decree on The Protection and Vehicles Facilitation No. 12302/ MPWT dated 7 September 2009

3.2. Ambient Air Quality standards

Lao PDR has not adopted ambient AQ standards but monitoring results are often compared with some standards which are much more lenient than WHO guidelines (see Table 3.1).

Table 3.1 Ambient AQ standards used for comparison with monitoring results in Lao PDR Pollutant

Parameter	Lao National Environmental Standard	WHO Standard	USEPA
PM_{10}, 24-hr	0.12 mg/m^3	0.05 mg/m^3 (WHO, 2005)	0.15 mg/m^3
NO_2, 24-hr	-	-	-
NO_2, 1 Year	-	-	0.053 mg/m^3

3.3. Management of Mobile Sources

There is no specific regulation that controls the emissions of pollutants from mobile sources. The EPL also does not stipulate any specific provisions on this sector. The Transport Policy however of the Ministry of Public works and Transport (MPWT) has also set forth policy objectives and statements strongly supporting cleaner transport technology and mode shifting to more sustainable modes. The main environmental objectives of the MPWT include reduction of emissions from vehicles, reduction of noise as well as reduction of accidents. The MPWT also has adopted the following strategies (Table 3.2):

Table 3.2 MPWT transport strategies

Area	Strategy
Non-motorised transport	Promotion of non-motorised transport
	Improve safety and security
Public transport	Improve comfort
	Reduce walking distances to public transport
	Decrease travel times
	Increase service frequency
	Improve reliability and punctuality
	Provide customer information systems
	Introduce convenient fare systems
	Introduce high-capacity vehicles, where appropriate
	Integrate public transport fully with other modes
	Use cleaner fuels for public transport
	Integrate land-use and public transport planning
	Establish appropriate institutional structures for managing public transport
Private vehicle restriction measures	Provide priority for public transport in road space
	Reduce private vehicle usage through internalisation of impacts
	Introduce greater parking restrictions
	Examine potential for higher vehicle import taxation and petrol taxation

Although there is a vehicle registration system in place in Lao PDR, compliance with any emissions standards does not seem to be a legislated requirement.

Considering that the fuel for automobile use in the country is imported, it is highly probable that the automotive gasoline in use in Lao PDR is lead-free.

3.4. Management of Stationary Sources

Although Lao PDR does not have a large number of large industries, industrial air pollution from stationary sources are also managed by MONRE and the Ministry of Industry and Commerce. Stack monitoring of industries such as cement factories are also being conducted to ensure that these industries do not pollute the atmospheric environment of the country.

The environmental impact assessment (EIA) system requirements of the country for industries and establishments also are a way to monitor and regulate air pollution from the industry. The EIA system utilized in Lao PDR however is still informal and ad hoc in nature (Tan, 1998).

4. Conclusion

Acid deposition status and its negative impact still can be accepted in Lao PDR. However, the Water Resources and Environment (MONRE) as the agency is responsible for environment quality protection at the national level. Furthermore, the government has established and implemented some programs below:

- Accessed the United Nations Framework Convention on Climate Change (UNFCCC) in 1995 and is also a signatory to the Kyoto Protocol which it was accessed in 2003.
- Completed the "National Environmental Standard" in January 2010. The standard covers ambient air, water and soil quality and emissions sources from factories and in-use motor vehicles.
- Set up the Climate Change Steering Committee, Technical Working Group and established Climate Change Office.
- Set up the Cleaner Production Project and operated by Ministry of Industry and Handicraft;
- Formulated the Sustainable Transport Strategy up to the year 2020.
- Developed the National Environment Strategy up to the year 2020 and National Environment Policy.

As a least, developed economy which is still highly agriculture based, Lao PDR's environmental challenges are just beginning. Most of these problems however relate mostly to exploitation of natural resources in the rural areas. These problems include deforestation, solid degradation and loss of biodiversity and forest cover.

Since Lao PDR has still only small urban coverage, and industrial pollution is still generally negligible, addressing urban environmental problems is still not a priority for the government. Even in the urban centers, the major environmental challenges are not directly air quality management related – water, sanitation and solid waste.

Despite the general perception that air quality in the country is still generally good and an air quality management system is still not major requirement, results of limited monitoring conducted in Vientiane already suggest that the city has PM pollution problems as shown in Table 2.4 and Figure 2.4. The lack of technical scientific understanding on the status of air quality and their specific sources in the country will make it difficult for the government to address this PM problem. To dissolve the problem, $PM_{2.5}$ monitoring started in 2018. There is thus a need to start air quality management with at least a basic understanding of the country's air pollution problem through air quality monitoring and compilation of emissions inventory even on ad hoc project basis. Moreover,

the Lao PDR should participate the Acid Deposition in East Asia (EANET) in order to steadily and effectively manage its air quality, specifically in the key urban areas, which would contribute to the Program implementation.

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National Assessment on Acid Deposition in Malaysia

1. Basic Information on National Monitoring Activities

1.1 Outline of Acid Deposition Activities and National Monitoring Plan

Malaysia had participated in the preparatory phase of the Acid Deposition Monitoring Network in East Asia (EANET) during 1998 – 2000 and ever since jointly implemented EANET activities on a regular basis since 2001. Presently the Ministry of Environment and Water is the appointed National Focal Point whereas the Malaysian Meteorological Department as the appointed National Center for EANET. Acid deposition monitoring in Malaysia encompasses five different environmental media, wet and dry deposition, soil and vegetation; and inland aquatic environments. The measured parameters and monitoring intervals for these environmental media are given in **Table 1**.

Table 1 Acid Deposition Monitoring Measurement Parameters and Monitoring Intervals

Items	Measurement Parameters	Monitoring Interval
Wet Deposition	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^-, CH_3COO^-, $HCOO^-$, $C_2O_4^{2-}$	2 - Weekly
Dry Deposition	**Gas**: SO_2, HNO_3, NH_3, HCl, **PM Components**: $NH4^+$, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^-	Weekly / Biweekly
Soil	pH (H_2O), pH (KCl) exchangeable (Na^+, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, H^+) exchangeable acidity	3 – 5 years
Inland Aquatic	Water Temperature, pH, Electrical Conductivity, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^-, PO_4^{3-}	6 times a year

1.2 Monitoring Program 2015 - 2019

1.2.1 Wet and Dry Deposition Monitoring

There are four monitoring sites for wet deposition and three monitoring sites for dry deposition in Malaysia which are designated as EANET monitoring sites. The four wet deposition sites are Tanah Rata Regional Global Atmospheric Watch (GAW) Station in Pahang, Petaling Jaya Regional GAW Station in Selangor, Danum Valley GAW Station in Sabah and the Kuching Meteorological Station in Sarawak. The three dry deposition sites are Tanah Rata Regional Global Atmospheric Watch (GAW) Station, Petaling Jaya Regional GAW Station and Danum Valley GAW Station. Collection of wet and dry samples at all these sites is conducted by the Malaysian Meteorological Department (MET Malaysia), while the Department of Chemistry Malaysia (DOCM) conducted the chemical analysis. The DOCM has also participated in all inter-laboratory comparison studies conducted by EANET from 2015 - 2019.

1.2.2 Soil and Vegetation Monitoring

Soil and vegetation monitoring is carried out at two locations, one in the Peninsular, and one in Sarawak. Soil and vegetation monitoring at the Pasoh Forest Reserve, Negeri Sembilan, Peninsular Malaysia is undertaken by the Forest Research Institute Malaysia (FRIM) while monitoring at the Universiti Putra Malaysia (Bintulu Campus) Rehabilitation Forest, Sarawak is conducted by the Universiti Putra Malaysia Bintulu Campus. Chemical analysis of samples collected is conducted at the respective surveyors' laboratory facilities. Soil and vegetation data were provided by Malaysia to EANET in 2015 and 2018.

1.2.3 Inland Aquatic Monitoring

One designated EANET monitoring site is presently operated in Malaysia and it is located at the Sungai Tembaling site, Danum Valley, Sabah, East Malaysia. Sample collection at this site is conducted by the Malaysian Meteorological Department staff. Sampling had been stopped temporarily in 2018 due to unforeseen circumstances, which since have been resolved. Nevertheless, inland aquatic sampling could be resumed as of early 2021 only due to the extent of theCovid-19 pandemic in Sabah. Samples collected are sent to Petaling Jaya, Peninsular Malaysia for chemical analysis. Chemical analysis, as with the wet and dry deposition is duly conducted at DOCM.

1.3 Monitoring Stations

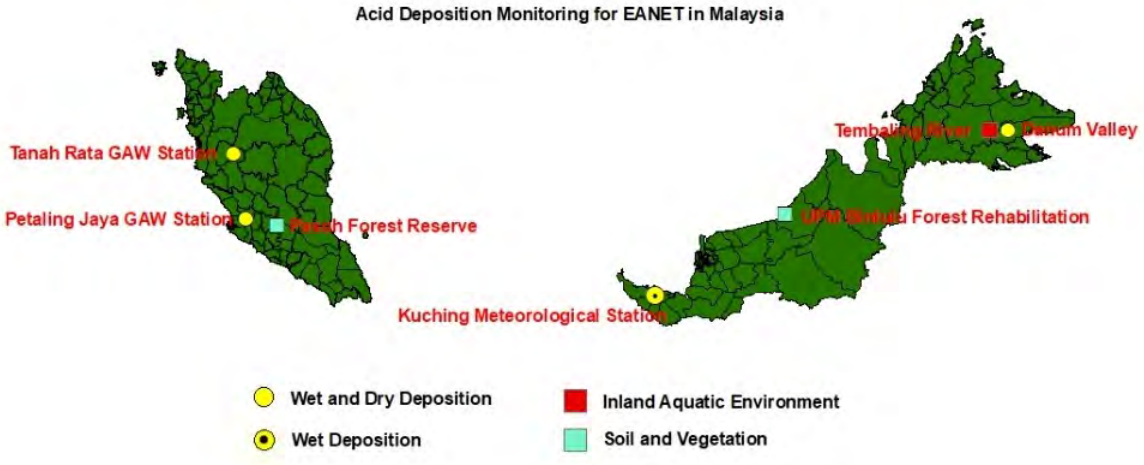

Figure 1. Locations of Acid Deposition Monitoring Sites in Malaysia.

Locations of the four wet and dry deposition monitoring sites, one inland monitoring site, and two soil and vegetation monitoring sites are shown in **Figure 1** above. The Danum Valley GAW Station, Tanah Rata GAW Station and Petaling Jaya GAW Station are designated as remote, rural and urban wet and dry deposition sites respectively, while Kuching is an urban site dedicated to wet deposition measurements only. In addition, geographical locations of the Pasoh and Bintulu Forest reserves and the Tembaling River Inland Aquatic site are given in **Figure 1**for greater clarity.

1.4 Sampling and Measurements

1.4.1 Wet Deposition Sampling and Analytical Methodologies

Wet deposition samples at all sites were collected using the wet-only sampler and acid precipitation sampler. The rainwater samples are collected on a weekly basis and stored in polyethylene bottles. Biocide (Thymol) is used to retard the degradation of organic compounds as well as ammonium and nitrate ions. The samples are then sent to DOCM for chemical analysis of the principal anions and cations. Analytical methods employed are in accordance with requirements of the technical manual and is given in **Table 1.2**.

Table 1.2 Characteristics of Wet Deposition Chemical Analytical Techniques Employed

Parameter	Measurement/analytical methods	Manufacturer/Type of equipment	Detection limit
pH	Glass Electrode	Mettler Toledo Education Line EL20	
Electrical Conductivity	Conductivity Cell	Mettler Toledo SevenEasy	0.06 µS/cm
SO_4^{2-}	Ion Chromatography	DIONEX USA / DX600 and ICS-2000 Anion System	0.04 µmol/L
NO_3^-			0.03 µmol/L
Cl^-			0.20 µmol/L
CH_3COO^-			0.05 µmol/L
$HCOO^-$			0.10 µmol/L
$C_2O_4^-$			0.07 µmol/L
NH_4^+	Ion Chromatography	DIONEX USA / DX600 and ICS-2000 Cation System	0.20 µmol/L
Na^+			0.40 µmol/L
K^+			0.08 µmol/L
Ca^{2+}			0.50 µmol/L
Mg^{2+}			0.40 µmol/L

1.4.2 Dry Deposition Sampling and Analytical Methodologies

Dry deposition samples were collected at Tanah Rata, Petaling Jaya and Danum Valley from 2015 to 2019. Three dry deposition approaches, Acid Precipitation Sampler based Dry Bucket, filter pack and passive sample are employed at each of these sites. Dry Bucket sampling at all these sites is carried out once a month. Filter pack and passive sampler sampling at Tanah Rata and Petaling Jaya were done weekly, whereas in Danum Valley it was done biweekly due to the remote locality of the station as well as low concentration of acid deposition at the surrounding area. The Dry Bucket, filter pack and passive sampler samplings were sent to the DOCM for analysis. The measurements and analytical methods are tabulated in **Table 1.3**.

Table 1.3 Characteristics of Dry Deposition Chemical Analytical Techniques Employed

Parameter	Measurement/analytical methods	Manufacturer/Type of equipment	Detection limit
SO_4^{2-}	Ion Chromatography	DIONEX USA / DX600 and ICS-2000 Anion System	0.010 mg/L
NO_3^-			0.006 mg/L
Cl^-			0.009 mg/L
NH_4^+	Ion Chromatography	DIONEX USA / DX600 and ICS-2000 Cation System	0.003 mg/L
Na^+			0.010 mg/L
K^+			0.003 mg/L
Ca^{2+}			0.020 mg/L
Mg^{2+}			0.010 mg/L

1.4.3 Inland Aquatic Sampling and Analytical Methodologies

Surface water samples were collected at 30 cm depth using a grab sampler 6 times a year, with the exception of the period from 2018 to 2020. The sampling point for Sungai Tembaling was at the estuary. The pH, electric conductivity and temperature measurements were carried out in situ. Water samples to determine Cation and Anion concentrations were collected in polyethylene bottles and sent to the DOCM for analysis. Parameters to be measured for inland samples are listed in **Table 1.4**.

Table 1.4 Characteristics of Inland Aquatic Chemical Analytical Techniques Employed

Parameter	Measurement/analytical methods	Manufacturer/Type of equipment	Detection limit
pH	Glass Electrode	Mettler Toledo Education Line EL20	
Electrical Conductivity	Conductivity Cell	Mettler Toledo SevenEasy	0.06 µS/cm
Alkalinity	Titration by burette with pH meter	Eutech Instrument pH1500 CyberScan	0.01 meq/L
SO_4^{2-}	Ion Chromatography	DIONEX USA /ICS - 1000 Anion System	0.03 mg/L
NO_3^-			0.02 mg/L
Cl^-			0.004 mg/L
PO_4^{3-}			0.02 mg/L
NH_4^+	Ion Chromatography	DIONEX USA / DX - 600 and ICS -2000 Cation System	0.003 mg/L
Na^+			0.01 mg/L
K^+			0.003 mg/L
Ca^{2+}			0.020 mg/L
Mg^{2+}			0.01 mg/L

1.4.4 Submission of data to the Network Center

The monitoring data from the respective agencies were submitted to MetMalaysia. MetMalaysia compiled, validated and submitted the data to National Focal Point for approval before submission to the Network Center. Malaysia also participated in the Inter-laboratory comparison (ILC) project on wet deposition, dry deposition, soil and inland aquatic environment. The ILC project is a round-robin test which involves 4 analytical laboratories as **Table 1.5** below.

Table 1.5 Inter-Laboratory Comparison (ILC) Project For Malaysia

DEPARTMENT	CODE	Type of ILC Project			
		Wet	Dry	IA	Soil
Division of Environmental Health, Department of Chemistry MALAYSIA (DOCM)	MY01	■	■	■	
Universiti Putra Malaysia, Campus Bintulu	MY04				■
Soil Laboratory, Forest Research Institute Malaysia (FRIM)	MY05				■

2. State of Acid Deposition in Malaysia

Wet Deposition

The acid deposition assessment of Malaysia for this PRSAD report will focus on analysis of wet deposition measurements. Wet deposition sampling undertaken at all the four EANET stations, Petaling Jaya, Tanah Rata, Kuching and Danum Valley is used to assess the situation with Malaysia. The assessment will involve pH values, cations sodium, potassium, magnesium, calcium and ammonium; and anions nitrate, sulphate and chloride.

Data trend analysis will involve both long-term and relatively shorter-term trends. Long-term trends will involve data analysis of data available since implementation of the sampling at the respective stations. Shorter trend analysis will involve data obtained during the last five years at the respective sites. Long-term trends were obtained using the annual means while the short term trend via employing monthly distribution of the data. The period for which data is available with regard to long-term trends differs a bit between the stations. Long-term data is available from the year 2000 onwards for Cameron Highlands and Petaling Jaya, while it is available from 2005 and 2008 for Danum Valley and Kuching respectively. Present status of acid deposition is assessed using five-year period data from 2015 to 2019.

2.1 Annual Trends of Wet Deposition

Annual trends for selected anions and cations are displayed in various figures from **Figure 2.1** to **Figure 2.9**. Interpretation of **Figure 2.1** will require **Figure 2.7** and **Figure 2.8** representing annual trends of both nitrate and sulphate respectively to be analyzed together. This is due to solubility of both nitrate and sulphate forming nitric and sulphuric acids respectively increasing the acidity of

rain water.

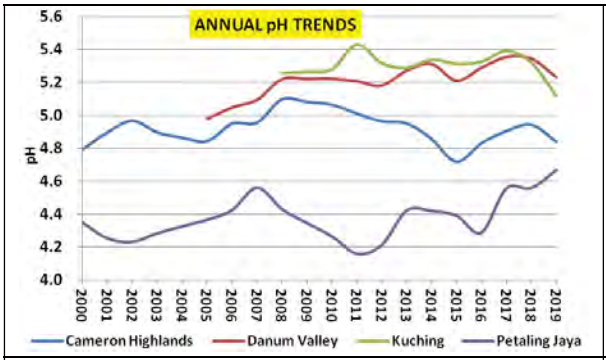

Figure 2.1. Annual pH Values.

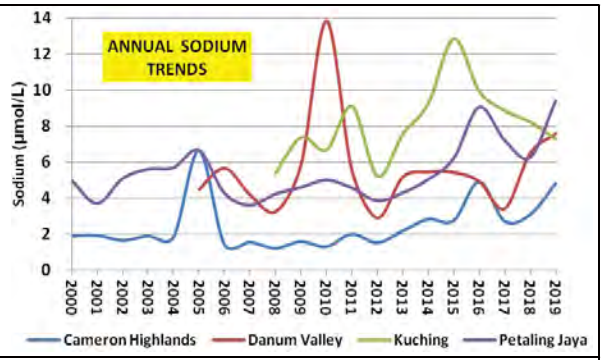

Figure 2.2. Annual Sodium Concentrations (µmol/L).

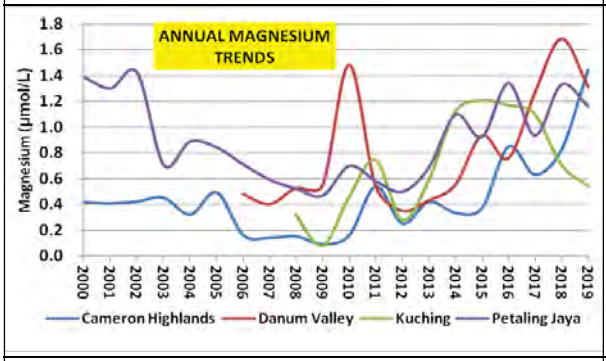

Figure 2.3. Annual Magnesium Concentrations (µmol/L).

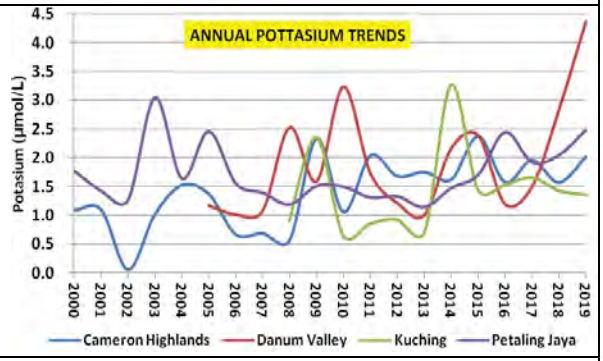

Figure 2.4. Annual Potassium Concentrations **(µmol/L).**

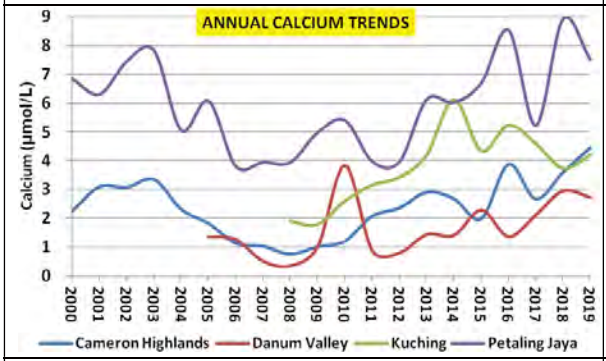

Figure 2.5. Annual Calcium Concentrations (µmol/L).

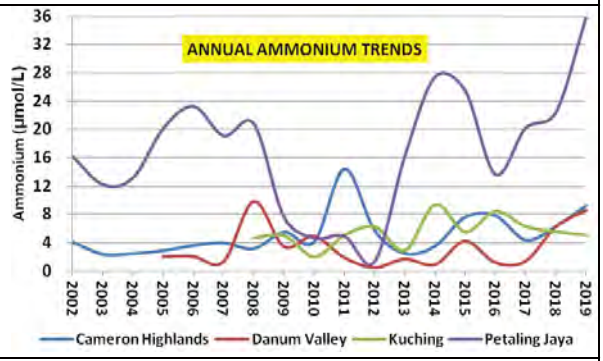

Figure 2.6. Annual Ammonium Concentrations (µmol/L).

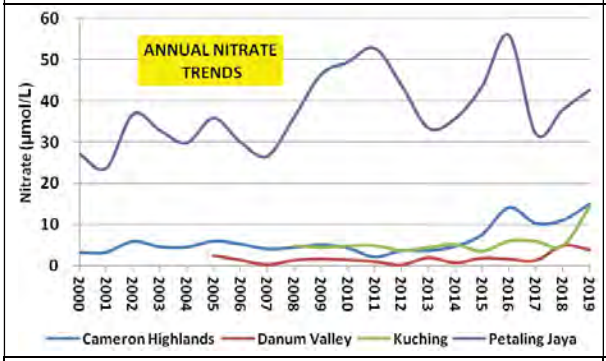

Figure 2.7. Annual Nitrate Concentrations (µmol/L).

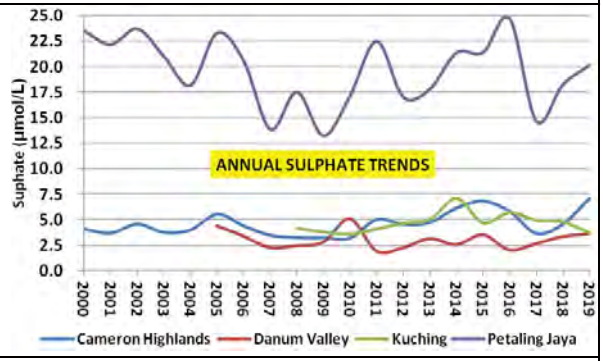

Figure 2.8. Annual Sulphate Concentrations (µmol/L).

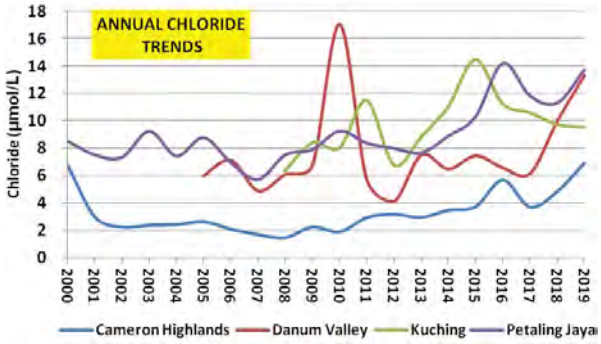

Figure 2.9. Annual Chloride Concentrations.

Expectedly acidity for Petaling Jaya (**Figure 2.1**) representative of an urban setting is highest among the four analyzed stations. This corresponds to the much higher concentration of nitrate (**Figure 2.7**) and sulphate (**Figure 2.8**) in Petaling Jaya compared to the other stations. Among the four stations there seems to be an overall reduction in acidity for Petaling Jaya and Danum Valley, with the trend more definitive over the last fifteen and ten years for Danum Valley and Petaling Jaya respectively. The reasons for this observation differ between both stations. The migration from Research Octane Number (RON) 92 to RON95 in 2009 and adoption of cleaner industrial technologies during the last ten years may be the main reasons attributed for the gradual reduction of acidity at Petaling Jaya. Whereas conversion from palm oil to reforesting of initially logged areas at the periphery of the protected buffer zone of the Danum Valley Forest Reserve sometime 2008 onwards could be the main contributing factor towards reducing of rainfall acidity.

Among Cameron Highlands, Danum Valley and Kuching, rainfall acidity in Cameron Highlands is significantly higher throughout the assessment period. Nevertheless, this significant departure is not obvious from nitrate and sulphate concentrations observed at Cameron Highlands and Kuching during the same period. The slight increase in nitrate concentration at Cameron Highlands compared to Kuching from around 2015 to 2018 (**Figure 2.7**) is not sufficient enough to explain this observation. A more plausible explanation would be the geographical valley conditions at Cameron Highlands and location at higher altitudes leading to lower surface temperatures and therefore clearly established low lying inversion layers. These conditions enhance entrapment of atmospheric pollutants nearer the surface.

Significant transboundary haze incidences in Malaysia were recorded in 2005, 2015 and 2019, while weak to moderate events were recorded during 2010 and 2011. Transboundary haze incidences of significance had generally affected the acidity of nearly entire Malaysia, sparing only the east of Sabah and southern Sarawak (**Figure 2.14**). A demonstration of this is the relative increase of acidity in all the stations around 2015 to 2016 (**Figure 2.1**). The impact was more significant in the Peninsular Malaysian stations, given that both the East Malaysian stations are in regions usually spared the main impacts as mention earlier. This is clearly reflected in the significant increase of nitrate and sulphate during the same period for Petaling Jaya and Cameron Highlands, compared to Kuching and Danum Valley (**Figure 2.7 & Figure 2.8**).

Another instance of significant effects of transboundary haze upon acid deposition was in 2019. All three stations, Cameron Highlands, Danum Valley and Kuching demonstrated increasing

acidity. Nevertheless, the reducing acidic tendencies at Petaling Jaya during the same period is an anomaly, and can be attributed to an increase of rainy days in the central region of the west coast of Peninsular Malaysia, leading to more frequent wash out of the acidic substances from the atmosphere. Effects of weak to moderate haze events demonstrate lesser spatial extent and can be limited to selected regions. Analyzing **Figure 2.1**, from 2010 to 2011 moderate haze events being limited to the west coast of Peninsular Malaysia, resulted in significant increase in rainfall acidity being limited to Petaling Jaya, while only to a lesser extent at Cameron Highlands. This observation is consistent with a significant increase of nitrate and sulphate during the period only being limited to Petaling Jaya, which is a station located along the west coast of Peninsular Malaysia.

Analyzing annual sodium concentrations (**Figure 2.2**), all four stations demonstrate a general increasing trend from around 2012 onwards, with the trend being more significant for both Peninsular Malaysian stations compared to East Malaysia. Nevertheless, the concentration of sodium is highest for Kuching among all the four stations during the analyzed period. Although sodium is used as a soil neutralizing agent in agriculture, Kuching recording the highest concentrations during the period of analysis might be primarily due to anthropogenic emissions related to power and domestic consumptions, as the last decade was synonymous with very rapid urban development occurring at Kuching.

As with Sodium concentrations, since 2012 a similar distinct increasing trend, specifically for Petaling Jaya, Cameron Highlands and Danum Valley is observed with regard to magnesium (**Figure 2.3**). Nevertheless, for Kuching, the trend tapers off as of 2015. Among the non agriculture related anthropogenic sources of magnesium are constructions and solid fuel applications such as coal. Reports from Sarawak (L. K. Swee, 2017) demonstrate that efforts to move away from coal-based power generation in Sarawak were already taking place in 2017. This motivation could have resulted in the significant drop in magnesium observed from 2017 to 2019 at Kuching. Among all the four stations, the increase of magnesium at Danum Valley since 2012 is most significant. This could be attributed to a combination of both coal-based power plants at Lahad Datu and magnesium-based fertilizers at palm oil estates on the periphery of the Danum Valley Reserve Forest.

Main anthropogenic sources for potassium are similar with magnesium, namely agriculture and solid based fuel applications such as coal. In addition, potassium particles are also among the major PM2.5 constituents during haze incidences (Liu *et al*, 2016). There is no observation of significant long-term distinct trends with regard to potassium (**Figure 2.4**) at all the four stations. A slight increasing trend from 2002 that tapers off at around 2016 is observed for Cameron Highlands. The source for this trend would probably be fertilizers, as the main economic activities at Cameron Highlands are agriculture and tourism. Among all four stations, the most significant annual variation is observed for Danum Valley, and the significance seems to drawing consistency with transboundary haze incidences that have occurred.

Main anthropogenic sources for calcium are stationary combustion in the manufacturing industries, residential combustion and mineral mining. Among the four stations, highest concentration of

atmospheric calcium is observed at Petaling Jaya, whereas the lowest concentration is at Danum Valley (**Figure 2.5**). The reasons for the above are obvious due to Petaling Jaya being a manufacturing hub, while Danum Valley, being a remote station, the calcium there is probably a result of regional atmospheric transport. Kuching being an urban development representation would be more representative of atmospheric calcium compared to Cameron Highlands. All the stations reflect an increasing trend from the early part of the last decade, and these trends are more significant at Petaling Jaya comparatively.

Main anthropogenic sources for ammonium are agriculture related, namely nitrogen-based fertilizer and livestock. Generally, concentrations for atmospheric ammonium are highest at Petaling Jaya, except for the period around 2010 to 2012 (**Figure 2.6**). The reasoning for this anomaly is probably the significant impact of moderate haze being limited to only the west coast of Peninsular Malaysia, thereby resulting in the significant increase of nitrate and sulphate only at Petaling Jaya (**Figure 2.7** & **Figure 2.8**). The resulting acidity consistently being neutralized by the alkaline ammonium duly might have resulted in reduction of ammonium (**Figure 2.6**).

Main sources of atmospheric chlorine include wild fires and anthropogenic sources such as coal combustion, biomass burning and industrial emissions (Luo *et al*, 2019). Among all the stations lowest concentrations of chlorine was observed Cameron Highlands, probably due to none of the above activities occurring significantly at Cameron Highlands. As of the earlier part of the last decade, an increasing trend is observed at Cameron Highlands, Petaling Jaya and Danum Valley, with the trend being more significant for the former two stations. Conversely a decreasing trend is observed at Kuching from 2015 onwards.

Some relatively consistent patterns observed in various figures from **Figure 2.1** to **Figure 2.9** required to be analysed in greater depth as the explanations are not readily forth coming. Firstly, the annual variations of ammonium (**Figure 2.6**) for Danum Valley and Kuching in opposite poles throughout the analysed period may reflect aspects of interplay between the summer and winter boreal winds in Kalimantan requiring greater understanding. Another is the significantly high values of sodium, magnesium, potassium, calcium, sulphate and chloride at Danum Valley from specifically 2009 to 2011. The specific increase in ammonium (**Figure 2.6**) for Cameron Highlands from 2010 to 2012 and sodium (**Figure 2.2**) from 2010 to 2012 observation also is not trivial to explain. A specific drop in concentrations for magnesium, potassium and calcium at Petaling Jaya for an extended period approximately from 2002 – 2003 to around 2016, and similarly for sodium from around 2005 to 2016 may be due to two significant haze incidences that two place in 2005 and 2015.

2.2 Present Status of Wet Deposition

Short-term or present status data analysis was conducted for pH measurements, nitrate, sulphate and ammonium employing box plots containing data for a period of five years from 2015 to 2019. The box plot monthly analysis is given in **Figure 2.10**, **Figure 2.11**, **Figure 2.12** and **Figure 2.13** with regard to pH measurements, nitrate, sulphate and ammonium respectively. A significant increase in acidity is observed during the Boreal winter monsoon for all the four stations (**Figure**

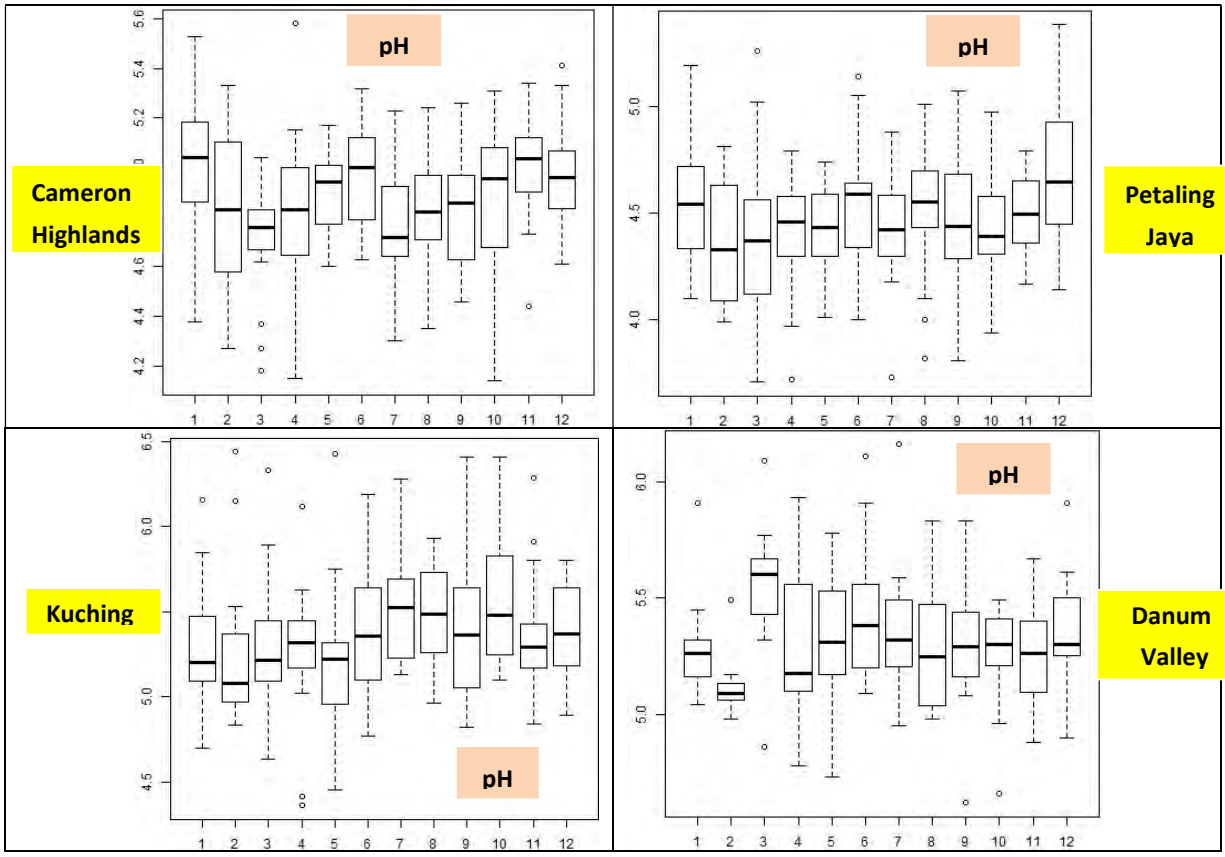

Figure 2.10. Monthly Box-Plot Distributions of pH Values from 2015 – 2019 for Cameron Highlands, Petaling Jaya, Kuching and Danum Valley.

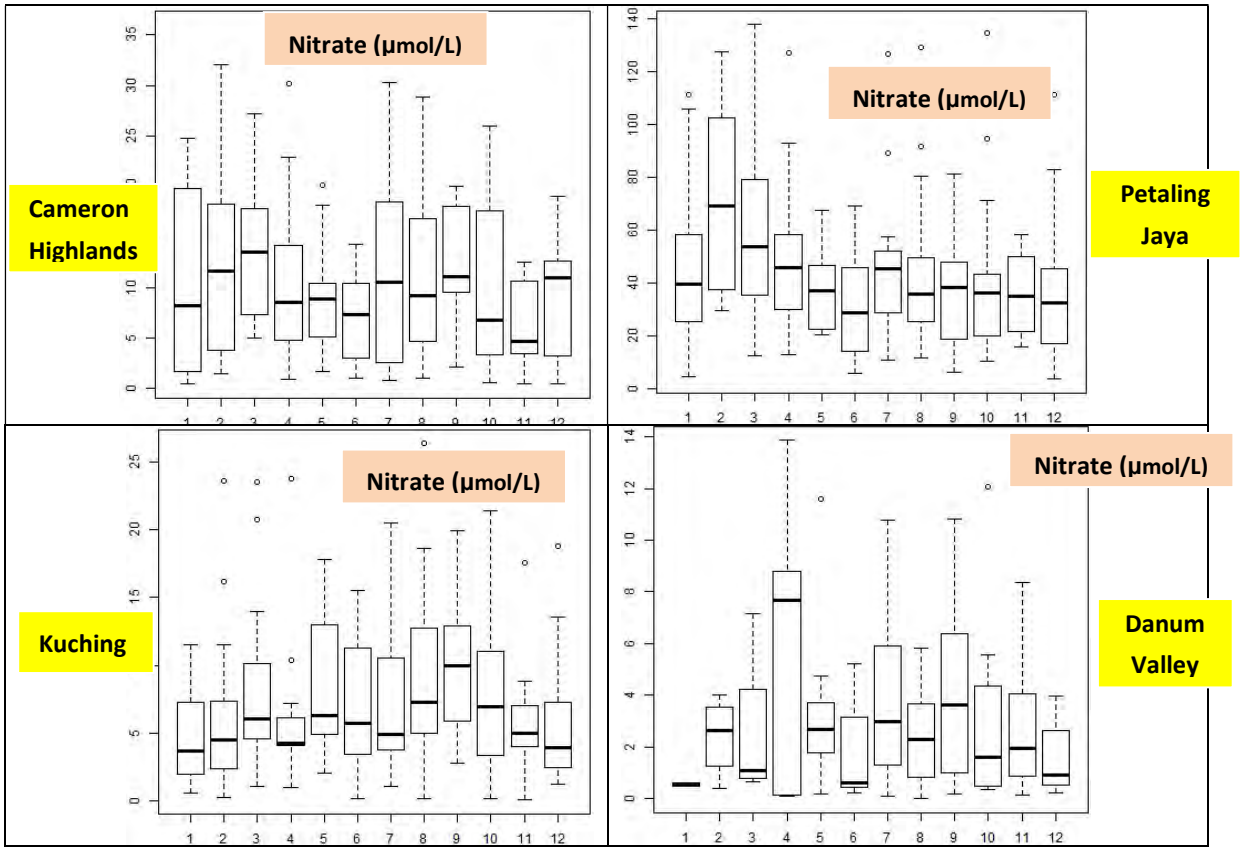

Figure 2.11. Monthly Box-Plot Distributions of Nitrate Concentrations (µmol/L) from 2015 – 2019 for Cameron Highlands, Petaling Jaya, Kuching and Danum Valley.

2.10). Annual significantly low pH observations were recorded in March for Cameron Highlands, while lowest pH observations were recorded in February for Petaling Jaya, Kuching and Danum Valley. At Cameron Highlands, atmospheric acidity in March is only very slightly higher than the lowest pH ranges recorded for Cameron Highlands, which is during July.

A seemingly contradictory but significant observation compared to the above is the recording of lowest atmospheric acidity for Cameron highlands, Petaling Jaya and Danum Valley stations, which is also during the Boreal winter monsoon. Highest pH observations were recorded in January for Cameron Highlands, December for Petaling Jaya, and March for Danum Valley. The exception here is Kuching, whereby the atmosphere is observed to be least acidic during July (**Figure 2.10**). While the trend of moving from a less acidic atmosphere to a more acidic atmosphere from the Boreal summer to the Boreal winter is distinctly clear with regard to Kuching, such is not the case with the other stations. Two distinct cycles representing progression from minimum atmospheric acidity to maximum acidity, or vice versa is clearly observed for Cameron Highlands. No such clear trend of atmospheric acidity tendency is observed for Danum Valley and Petaling Jaya, with monthly atmospheric acidity fluctuations from February to April being the most significant observations for the former, and a shorter interspersed atmospheric acidity cycle of three months between the months of June to August between two longer cycles seems to be observed for the latter.

Both **Figure 2.11** and **Figure 2.12** demarcating annual monthly variation of nitrate and sulphate will need to considered in order to explain the observations made with regard to atmospheric acidic trends in Malaysia discussed earlier. Maximum monthly concentrations of atmospheric nitrate (**Figure 2.11**) and very high concentrations of sulphate (**Figure 2.12**) in March at Cameron Highlands were representative of the very high acidic conditions observed during July. Additionally lowest annual pH readings recorded in July for Cameron Highlands coincided with maximum annual sulphate concentrations and a five-month maximum nitrate concentration in July. Least acidic conditions in January for Cameron Highlands coincided with among the lowest monthly concentration of sulphate and a significantly lower concentration of nitrate observed during the same period. The annual double cyclic variation of acidity in Cameron Highlands (**Figure 2.11**) is a contribution of both nitrate and sulphate concentrations, with nitrate being the main driver for certain months, and sulphate the main driver for certain months.

Maximum monthly concentrations of atmospheric nitrate (**Figure 2.11**) and sulphate (**Figure 2.12**) in February at Petaling Jaya were representative of the most annual acidic conditions observed at Petaling Jaya, which is during February. Annually least acidic conditions in December for Petaling Jaya coincided with among the lowest monthly concentrations of both sulphate and nitrate observed during the same period. Similarly, the significant increase in pH in June for Petaling Jaya is captured by the significant drop in atmospheric nitrate and sulphate during the same period. While the significant drop in acidity at Petaling Jaya from October to December is mainly driven by a reduction in sulphate concentration, the variation in pH during the other months are mostly observed to be contributed significantly by both nitrate and sulphate (**Figure 2.11 & Figure 2.12**).

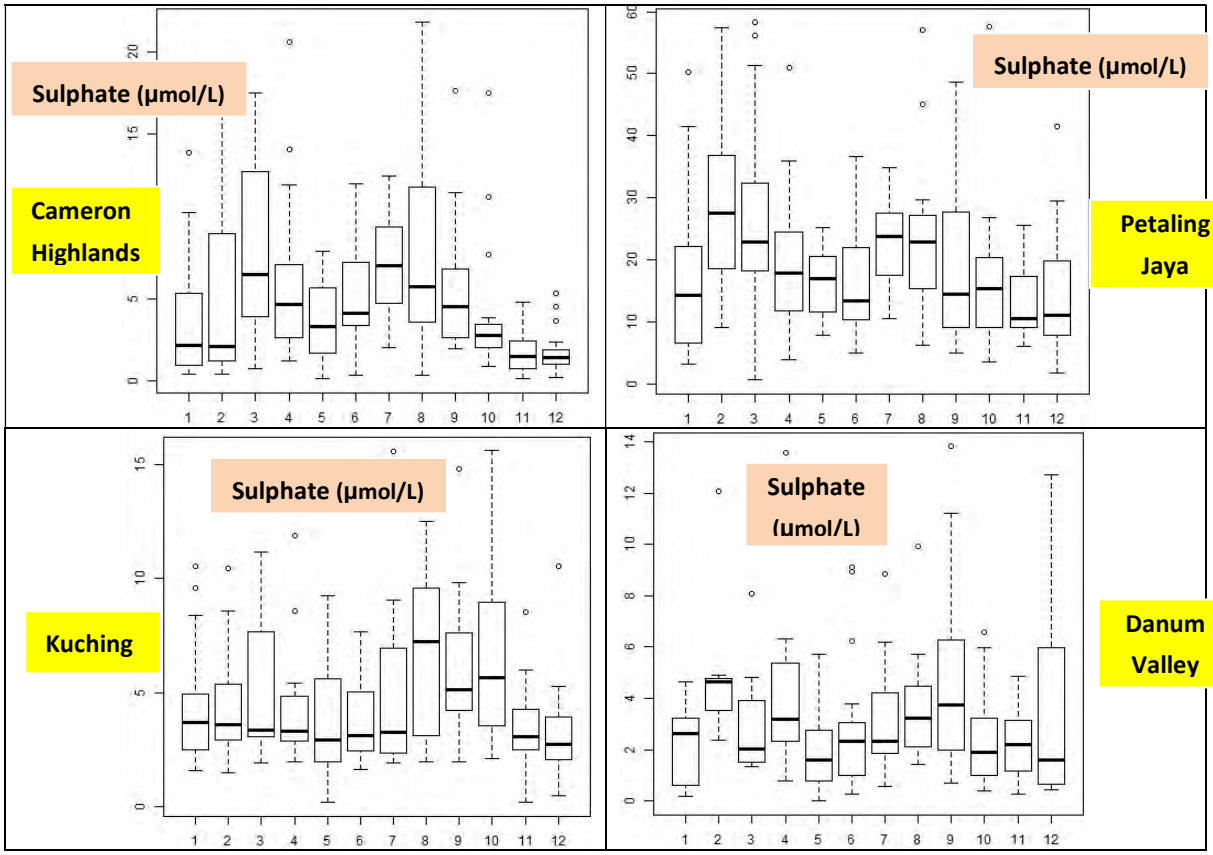

Figure 2.12. Monthly Box-Plot Distributions of Sulphate Concentrations (µmol/L) from 2015 – 2019 for Cameron Highlands, Petaling Jaya, Kuching and Danum Valley.

Maximum monthly concentration of atmospheric sulphate (**Figure 2.12**) is in February for Danum Valley. The monthly maximum nitrate concentration during the Boreal winter monsoon for Danum Valley is also in February (**Figure 2.11**). Both of these observations provide justification for the maximum acidity observed in Danum Valley in February. The significant local minimum sulphate and nitrate concentration in March are responsible for the annual minimum acidity observed for Danum Valley. Maximum and minimum annual nitrate concentrations for Danum Valley are observed on April and January respectively.

While monthly minimum atmospheric nitrate concentrations in Kuching are observed in January, the three months December, January and February represent the extended period during which nitrate concentrations are minimum throughout the year (**Figure 2.11**). Maximum nitrate concentration for Kuching is observed in September. Similarly, while maximum sulphate concentration in Kuching is observed in August, the three months August, September and October represent the extended period during which sulphate concentrations are significantly higher compared to the remaining months (**Figure 2.12**). Minimum sulphate concentrations for Kuching are observed in December. The inverse influence of nitrate and sulphate concentrations upon acidity of rain water observed at Cameron Highlands, Petaling Jaya and Danum Valley; seem not to be entirely the case for Kuching.

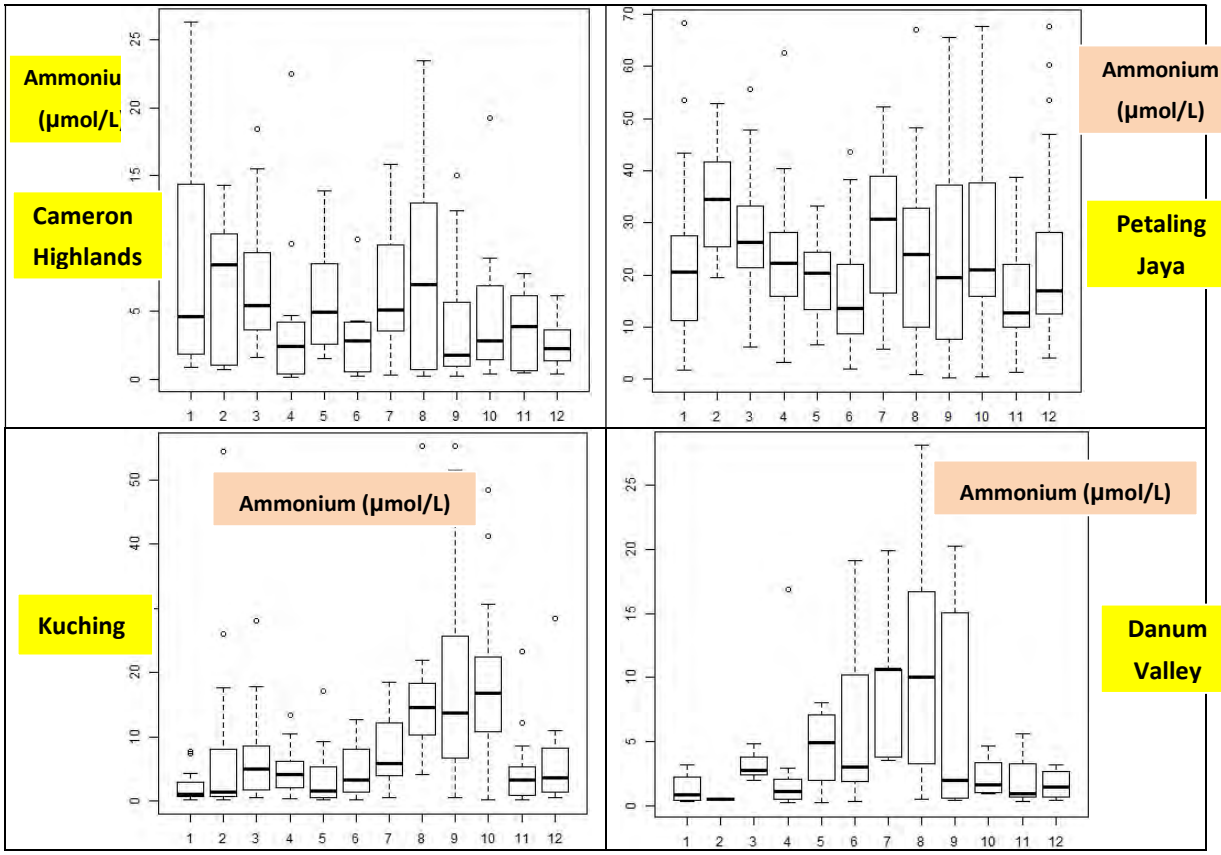

Figure 2.13. Monthly Box-Plot Distributions of Ammonium Concentrations (µmol/L) from 2015 – 2019 for Cameron Highlands, Petaling Jaya, Kuching and Danum Valley.

Relating the pH trend for Kuching between August to October to nitrate and sulphate concentrations, it is observed that nitrate is the main driver for the pH trend above, as nitrate seems to be consistent with the inverse relationship between nitrate concentration and pH observations, while sulphate concentrations does not do so. Significantly deviating from the above premise, the most acidic conditions in Kuching annually, which is observed during February, can't be explained by low concentrations of both sulphate and nitrate during the same period. In this case, the potential for chlorine concentrations originating primarily from coal-based power plants to explain the above anomaly needs to be given adequate consideration. Nevertheless, with regard to least acidic conditions observed in July, the regular inverse relationship applied is consistent, as low concentrations of both nitrate and sulphate are observed during the same period.

Monthly trends for ammonium concentrations for the four stations are demonstrated in **Figure 2.13**. Highest concentration of ammonium at Petaling Jaya is observed in February, followed by a consistent decreasing trend for the next four months leading to a minimum ammonium concentration being are observed in June. The lowest ammonium concentration for Petaling Jaya is observed during November, though concentration of ammonium in June and November are not trivial to differentiate. Ammonium concentration at Cameron Highlands seems to be driven by regular three-monthly periods annually. Highest and lowest concentrations of ammonium at Cameron Highlands are observed during February and September respectively.

While for Peninsular Malaysia the presence of minimum – maximum concentration cycle is quite

evident (**Figure 2.13**), varying only by duration of the cycles, in East Malaysia such a cycle is not evident and there is a clear demarcation of continuous periods of higher and lower concentrations of ammonium. Ammonium concentration is significantly higher from August to October for Kuching compared to the rest of the year. Highest concentration of ammonium for Kuching is observed in September while the lowest is in January. At Danum Valley, ammonium concentrations are significantly higher from May to September compared to the rest of the year. Highest and lowest concentration of ammonium at Danum Valley is observed during August and February respectively (**Figure 2.13**).

In many instances concentrations of atmospheric sulphate, nitrate and ammonium (**Figure 2.11, Figure 2.12 & Figure 2.13)**) display trends specific to either the Boreal summer or winter. Nitrate variations (**Figure 2.11**) are significantly sinusoidal during the Boreal winter compared to the Boreal summer at Cameron Highlands. Nitrate concentrations at Kuching and Danum Valley are significantly higher during the Boreal summer, while it is significantly higher during the Boreal winter for Petaling Jaya. Sulphate concentrations (**Figure 2.12**) at Cameron Highlands and Kuching are significantly higher during the Boreal summer, while there is a significant increase in sulphate concentration for Petaling Jaya during the last two months of the Boreal winter. Ammonium concentrations (**Figure 2.13**) are significantly higher during the Boreal summer at Kuching and Danum Valley. Ammonium concentration distribution at Cameron Highlands is significantly different during the first three months of the Boreal winter compared to the later three months.

The observations above demonstrate the significance of transboundary transport of pollutants driven by the seasonal wind patterns in the region. Therefore, it is necessary to comprehend the variation from one season to another when attempting to understand the pollutants trends observed. The sudden increase or decrease in pollutants in the region during the months of February and March will probably be influenced by the changing wind patterns from north and north easterly coming in to the South China Sea to formation of cross equatorials across the South China Sea as the monsoon trough progresses southwards. This modifies the regular wind pattern across East and Peninsular Malaysia, thereby influencing transboundary and regional pollutant transport in to East and Peninsular Malaysia.

2.3 Effect of Transboundary Haze on Acid Deposition in Malaysia

An overall geographical distribution of pH and nitrate concentration throughout Malaysia for the months June, August and September is investigated to understand the impacts of transboundary haze upon acid deposition in Malaysia. The investigation is undertaken using data obtained during the most recent severe haze episode to impact Malaysia, which was in 2019. The investigation is conducted by comparing nitrate and pH observations during the month of June with nitrate and pH observation during August and September respectively. All the respective images for the months of June, August and September are displayed in **Figure 2.14** and **Figure 2.16**.

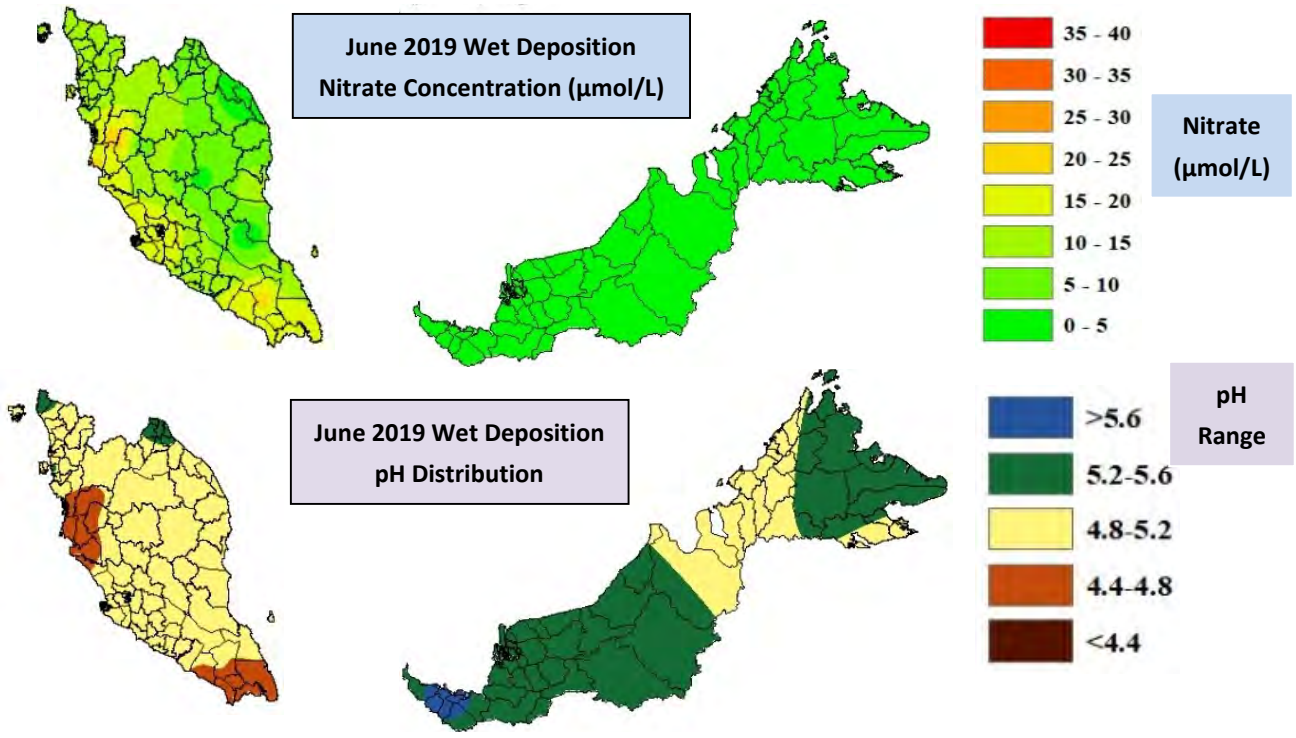

Figure 2.14. Distribution of Nitrate Concentrations (µmol/L) and pH for June 2019 in Peninsular Malaysia and East Malaysia.

The nitrate and pH measurements were obtained from a combination of Acid Precipitation Samplers (APS) and Wet-Only Rainfall Samplers (WORS) operated throughout Malaysia under the Acid Precipitation Monitoring Network under the supervision of the Malaysian Meteorological Department (MMD). In 2019 there were 17 and 11 stations in Peninsular Malaysia and East Malaysia respectively. The process to improve the coverage in East Malaysia is on-going and there are now 13 air precipitation stations there. Data sampling and quality protocols for all stations follow the technical requirements stipulated for the four EANET stations. The map displayed in Figure 2.14 is obtained via interpolation of the undertaken weekly sampling. While the coverage needs to be better to obtain better representation rain water acidity nationally, especially for East Malaysia, nevertheless the measurement locations and period are consistent throughout the period from June to September, and therefore allows for justifiable comparison.

During June 2019 (**Figure 2.14**), the transboundary haze had not set in yet. During this period

nitrate concentrations were within 10µmol/L in East Malaysia. Rain water in East Malaysia generally registered pH values higher than 5.2 at most locations, with pH measurements between 4.8 to 5.2 being limited mainly to north Sarawak; and western and south-west Sabah. During the same period, nitrate concentrations in the east coast of Peninsular Malaysia is generally less than 10µmol/L, while for the west coast it ranges from 10µmol/L to 25µmol/L, with a few locations registering concentrations up 30µmol/L. Meanwhile pH measurements in the Peninsular during June indicate values above 4.8 in the east coast and between 4.4 and 5.2 in the west coast.

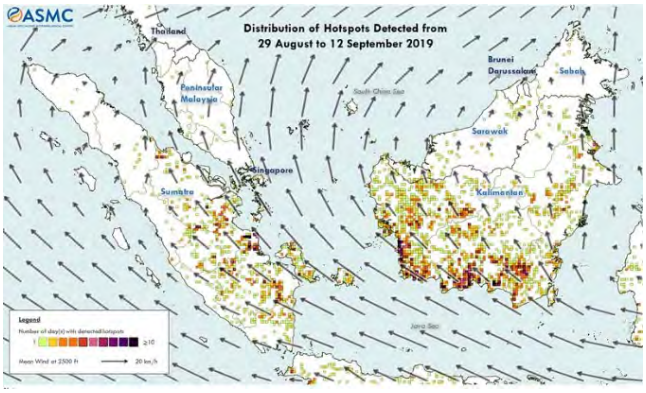

Figure 2.15: Hotspot Distribution in Sumatera and Kalimantan; and Seasonal Wind Distribution during Haze

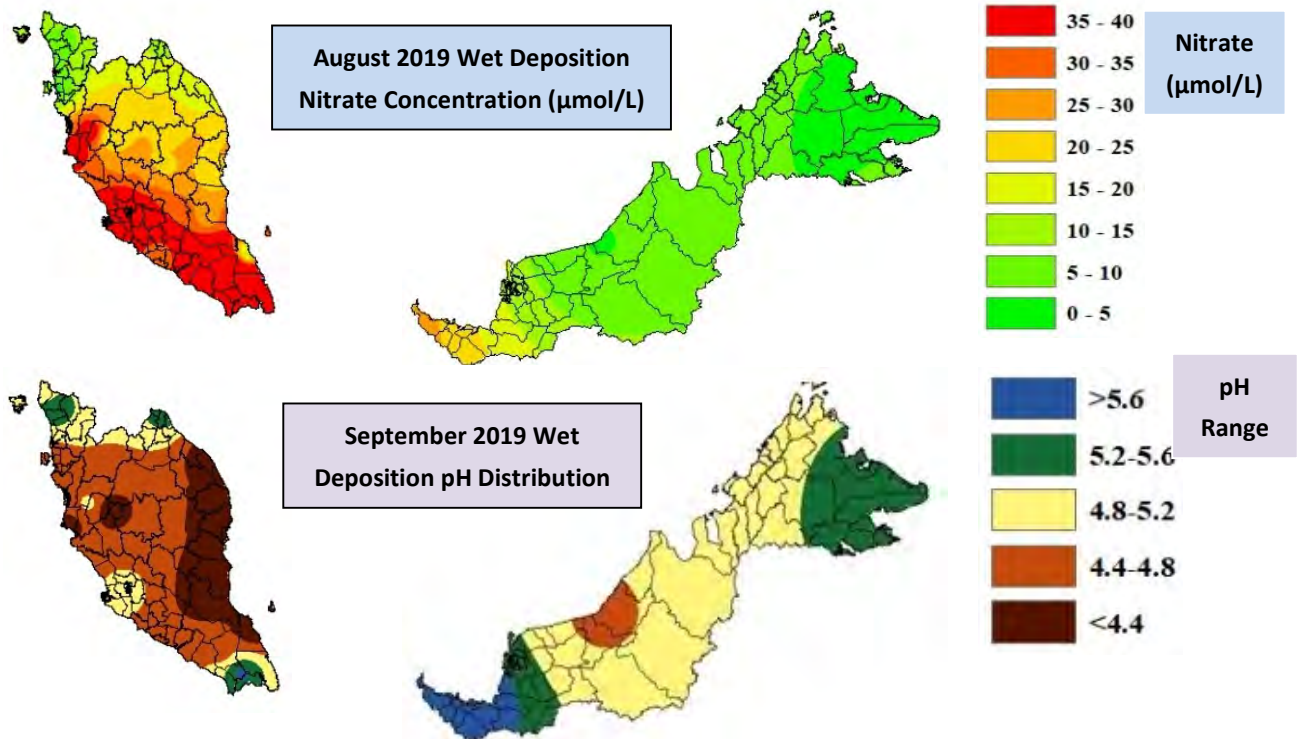

Figure 2.16. Distribution of Nitrate Concentrations (µmol/L) and pH for August and September 2019 in Peninsular Malaysia and East Malaysia.

Subsequently transboundary haze due to massive land and forest fires in Sumatra and Kalimantan, Indonesia in the months of July up to September of 2019 (**Figure 2.15**) had resulted in deterioration of air quality in Peninsular Malaysia and East Malaysia from August to September

2019. Southwesterly to southerly winds (**Figure 2.15**) had caused transboundary transport of haze pollutants from Kalimantan and Sumatera to East Malaysia and Peninsular Malaysia respectively. The impact of these pollutants upon acid deposition measurements in displayed in **Figure 2.16**.
The impact of transboundary haze from Kalimantan with regard to East Malaysia is to central and southern Sarawak. While nitrate concentrations in central Sarawak are around 5μmol/L to 10μmol/L, as we progress southward, nitrate concentration increases from around 10μmol/L to 25μmol/L for August 2019. The effect upon Central Sarawak is clearer in the pH imagery for September 2019. Interpolated pH values drop to 4.4 to 5.2 for central Sarawak post transboundary pollution (**Figure 2.16**). Given that the change in nitrate in Central Sarawak is not significant, the predominant driver for acidity increase in this region should be due to increase in sulphate. The unexpected reduction of acidity in Sarawak during this period is probably due to neutralization of the nitrate, and possibly sulphate by coal driven cation pollutants magnesium and potassium. The power plants in southwest Kalimantan and Sarawak mainly run-on coal.

The impact of transboundary haze from Sumatera in 2019 affected nearly the whole of Peninsular Malaysia, with only the northwestern and northeastern regions being spared. There is a significant increase of nitrate in Peninsular Malaysia during August (**Figure 2.16**) as the concentrations are in the range of 15μmol/L to 40μmol/L for the east coast of Peninsular Malaysia and 20μmol/L to 40μmol/L for the west coast of Peninsular Malaysia. Compared to rain water acidity in Peninsular Malaysia during June 2019, a significant increase in rain water acidity had been interpolated for September 2019 (**Figure 2.14** & **Figure 2.16**). The pH values of rain water in the east coast of Peninsular Malaysia has dropped very significantly up to below 4.4, and is even more acidic than rain water sampled in the west coast of the Peninsular. Acidity of rain water in the west coast had dropped in most places to the range of 4.4 to 4.8. As with the case of relatively urbanized southern Sarawak, a decrease of acidity and an absence of expected acidity increase are observed in southern and central west coast Peninsular Malaysia respectively. This unexpected observation may be due to southern Peninsular being an industrialized zone and palm oil plantation rich region. Therefore, ammonium and calcium from these industries, together with potassium as an important by-product of forest fires have all the potential to neutralize the acidity in rain water caused by the transboundary nitrates and sulphates. This can also be the reason pH values of rain water in central west coast Peninsular Malaysia did not deteriorate during the transboundary haze incident.

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NATIONAL ASSESSMENT REPORT FOR MONGOLIA

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1. Basic information on National Monitoring Activities

Geographically, Mongolia is landlocked, highly elevated in approximately 1500 m above the sea level, surrounded by high mountains and consists of taiga forest, steppe, semiarid, arid, and desert.

Generally, Mongolian climate is dry and cold continental which is characterized by small precipitation and huge diurnal range of temperature. Annual mean temperature varies from 8 to -10^{0}C, precipitation falls from 50 to 500 mm in the year.

1.1. Monitoring program

Wet and dry depositions monitoring at the urban monitoring site Ulaanbaatar has been carried out only from May to October every year and it has been suspended during the cold season due to a technical problem caused by climate conditions. The monitoring programs are shown in Table 1.

Table 1 The monitoring programs

Items	**Monitoring site**	**Monitoring period**	**Monitoring interval**	**Monitoring parameters**
Wet deposition	Terelj Ulaanbaatar	2016-2020	Daily (May to October)	pH, EC, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}
Dry deposition	Terelj Ulaanbaatar UB4	2016-2020	Biweekly Weekly Daily, Continuously 15 minutes	Gases: SO_2, HNO_3, HCl, NH_3 Aerosol: SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_2, NO_2, CO, PM_{10}, $PM_{2.5}$, O_3
Inland aquatic environment	Terelj river	2016-2020	6 times per a year	pH, EC, alkalinity, SO_4^{2-}, NO_2^-, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, PO_4^{3-}
Soil	Ulaanbaatar	2016-2020	Every 3-5 years	pH (H_2O), pH (KCl) Exchangeable acidity

1.2. Monitoring stations

a. Wet and dry deposition monitoring sites:

Ulaanbaatar-urban site, $47^0$55’13’’N, $106^0$54’43’’E, 1275 m ASL (above sea level).
The site is placed in the center of capital city Ulaanbaatar (on the building roof of the National Agency of Meteorology and Environmental Monitoring) and well isolated from intensive stationary sources of air pollution. Ulaanbaatar is a capital city of Mongolia. The city is located on the bank of the Tuul River and surrounded by four mountains.

Terelj – remote site, $47^0$59’00’’N, $107^0$27’04’’E, 1550 m ASL.
This site locates in the central part of Mongolia, in the western part of the Khentei mountain ranges and away from major industrial polluting sources. The nearest major city is Ulaanbaatar which is 50 km far to the southwest.

1.3. Sampling and Measurement

a. Sampling method and sample handling:

The wet-only sampler with refrigerator (collection diameter is 357 mm) which is manufactured by Ogasawara Co. Ltd is using as for rain sampling. The equipment is removed once a year before the frost time and kept in the storage during the winter season because it does not meet the operation conditions under the cold weather. After the winter season, the equipment is installed again, and samples are collected daily. During the winter, a plastic basket with 395 mm diameter was used for snow sample (bulk) collection at the Terelj site.

The sampler with four-stage filter packs MB-01T manufactured by Tokyo Dylec Co.Ltd and it use for the dry deposition monitoring. The first membrane filter collects particles, the second cellulose filter is designed for absorption of SO_2, HCl, HNO_3, and the third alkaline impregnated filter is for residual SO_2, HCl, and the fourth acid impregnated filter-for NH_3 absorption.

Wet and dry deposition samples at Terelj remote site are collected on-site and transported to the analytical laboratory twice per month by local staffs and then analyzed by the Central Laboratory of Environment and Metrology (CLEM). Samples at Ulaanbaatar urban site are handled by CLEM.

b. Measurements:

Table 2 Analytical method and equipment

Items	Monitoring parameters	Measuring method	Equipment
Wet deposition	pH	pH-meter	HANNA, edge
	EC	EC-meter	DS-12, Horiba
	SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}	Ion chromatography	ICS-1600, Dionex

Dry deposition	Gases: SO_2, HNO_3, HCl, NH_3	Ion chromatography	ICS-1600, Dionex
	Aerosol: SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}		
Inland aquatic environment	SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}	Ion chromatography	ICS-1600, Dionex
	Alkalinity	Titration	Titration with 0.02n H_2SO_4

2. State of Acid Deposition in Mongolia

2.1 Atmospheric deposition

2.1.1 State of wet deposition

The state of acid rain and chemical composition of rainwater is presented in this report for the central part of Mongolia during the period 2016-2020. The acid deposition monitoring sites are in central area of the country and the monitoring period was extended only from May to October every year.

***pH*:** The pH of rainwater was in the range from 4.00 to 7.43 in remote site Terelj. At urban site Ulaanbaatar city, the pH varied from 4.24 to 7.86 and the rain with pH below 5.0 was observed several times for the period between 2010 and 2020. The annual mean values of pH for the period 2010-2020 are given in Table 3. Ten years annual mean values of the wet deposition pH are compared by two sites in Figure 1. Regarding the result, Ulaanbaatar rainwater is weak acidic than the Terelj except last years.

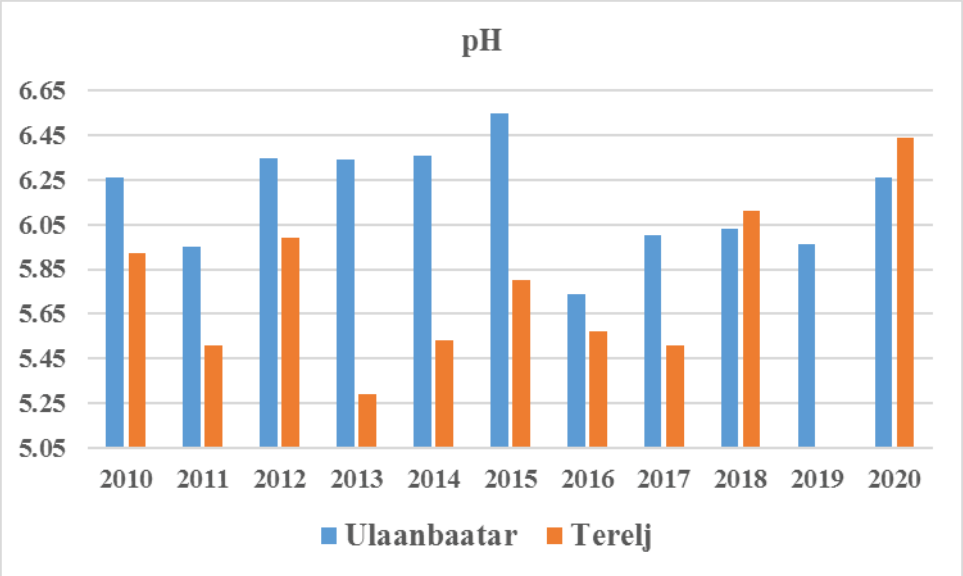


Figure1. The average of pH variations by ten years of urban and remote sites, Mongolia.

Electrical conductivity (EC): During the period of 2010-2020, a total of 292 and 346 samples from Ulaanbaatar and Terelj were collected and analyzed for electrical conductivity, respectively. EC values were of the range 0.17-18.35 mS/m and 0.20-31.20 mS/m at Ulaanbaatar and Terelj, respectively. The annual EC for the period 2010-2020 is presented in Table 3. The average of EC variations by ten years is presented in Figure 2.

Table 3 Annual means of the wet deposition pH and EC

Station	Year	pH			EC, mS/m		
		Annual mean	Min	Max	Annual mean	Min	Max
Ulaanbaatar	2010	6.26	5.33	7.32	2.88	0.38	14.26
	2011	5.95	4.76	6.77	3.09	0.53	10.18
	2012	6.35	4.69	7.22	2.42	0.42	9.19
	2013	6.34	5.35	**7.86**	4.30	0.69	16.79
	2014	6.36	5.23	7.11	2.82	1.08	6.27
	2015	6.55	6.03	7.23	3.37	1.47	6.89
	2016	5.74	**4.24**	6.54	4.13	**0.17**	**18.35**
	2017	6.00	5.22	8.36	2.08	0.38	7.01
	2018	6.03	5.04	6.66	1.85	0.25	7.52
	2019	5.96	4.71	6.69	5.68	0.43	10.16
	2020	6.26	4.89	6.91	2.40	0.81	7.76
Terelj	2010	5.92	4.63	7.29	3.34	0.35	**31.20**
	2011	5.51	4.20	6.40	1.64	0.47	8.37
	2012	5.99	4.57	6.68	1.97	0.27	14.79
	2013	5.29	4.17	6.65	2.06	0.27	8.11
	2014	5.53	4.30	6.29	1.37	0.28	4.77
	2015	5.80	4.75	6.63	3.20	0.25	14.66
	2016	5.57	**4.00**	**7.43**	3.19	0.24	13.55
	2017	5.51	4.13	6.11	1.38	**0.20**	4.79
	2018	6.11	5.01	6.81	1.45	**0.20**	4.92
	2020	6.44	5.45	7.36	2.87	0.69	20.60

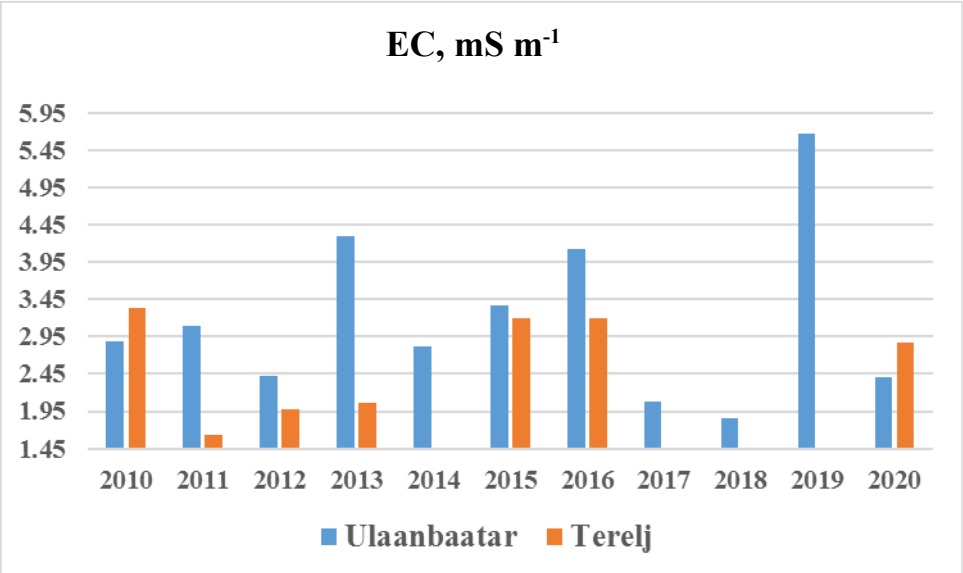


Figure 2. The average of EC variations by ten years.

Anions: Rainwater samples were collected in the period from 2016 to 2020 and analyzed for sulphate, nitrate and chloride ions using ion chromatography and the annual mean values are showed in the Table 4.

Table 4 Annual mean anion flux

Station	Year	SO_4^{2-}, µeq L^{-1}	NO_3^-, µeq L^{-1}	Cl^-, µeq L^{-1}
Ulaanbaatar	2016	268.1	37.8	4.7
	2017	69.2	30.4	3.6
	2018	68.2	25.1	4.3
	2019	139.6	44.7	10.4
	2020	77.4	43.4	4.6
	mean	**124.5**	**36.3**	**5.5**
Terelj	2016	283.0	48.6	9.7
	2017	27.1	43.5	8.7
	2018	53.2	25.4	5.8
	2020	95.3	39.8	5.6
	mean	**114.6**	**39.3**	**7.4**

According to the analysis, the contribution of sulphate to precipitation acidity was much higher than nitrate (Table 4).

Cations: The rainwater samples (2016-2020) were collected and analyzed for ammonia, sodium, potassium, calcium, and magnesium ions using ion chromatography and their annual mean values has shown in Table 5.

Table 5 Annual mean cation flux

Station	Year	NH_4^+ µeq L^{-1}	Na^+ µeq L^{-1}	K^+ µeq L^{-1}	Ca^{2+} µeq L^{-1}	Mg^{2+} µeq L^{-1}	H^+ µeq L^{-1}
Ulaanbaatar	2016	39.8	178.4	0.6	59.0	12.6	10.0
	2017	48.8	21.9	1.3	83.4	6.1	2.9
	2018	58.1	45.7	1.0	42.4	4.4	2.0
	2019	45.1	71.6	1.3	55.3	5.7	3.3
	2020	49.4	77.4	1.6	91.4	6.5	1.1
	mean	**48.2**	**79.0**	**1.2**	**66.3**	**7.1**	**3.9**
Terelj	2016	59.7	203.7	7.0	33.2	4.3	6.5
	2017	41.9	13.5	3.4	31.8	2.6	9.1
	2018	30.9	49.4	3.6	30.6	2.9	1.5
	2020	22.4	60.5	3.5	124.3	17.9	0.6
	mean	**38.7**	**81.8**	**4.4**	**54.9**	**6.9**	**4.4**

The sodium, calcium and ammonium ions mostly have been predominated among the cations in the rainwater. Major ions ccomposition of wet deposition of two sites is presented in Figure 3.

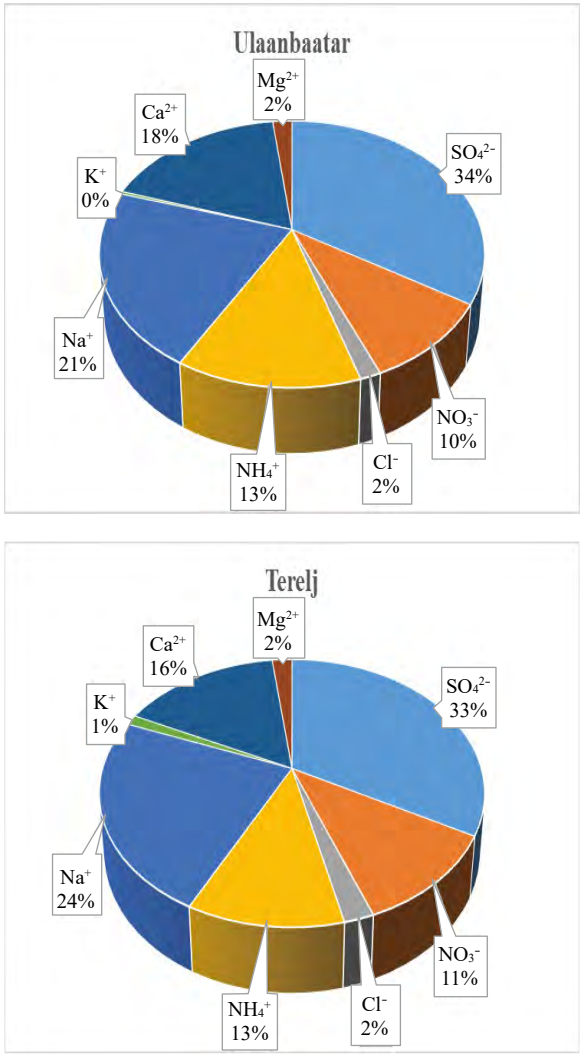


Figure 3. Major ions composition of wet deposition, 2016-2020, %.

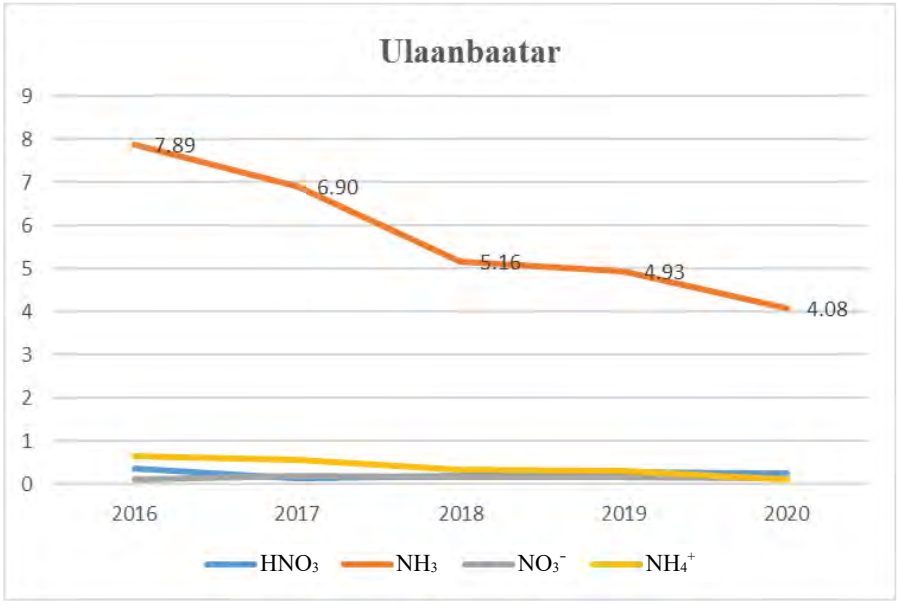
The dominant ion such as SO_4^{2-}, Na^+, Ca^{2+}, NH_4^+, NO_3^- was SO_4^{2-} (34%), followed by Na^+(21%), Ca^{2+}(18%), NH_4^+(13%), and NO_3^- (10%) in the wet deposition of Ulaanbaatar. The dominant ion (SO_4^{2-}, Na^+, Ca^{2+}, NH_4^+, NO_3^-) was SO_4^{2-} (33%), followed by Na^+(24%), Ca^{2+} (16%), and NO_3^- (11%) in the wet deposition of Terelj.

2.1.2 State of dry deposition

The mean annual concentrations of sulphur dioxide, nitric acid, hydrogen chloride and ammonia in the atmosphere of the urban site Ulaanbaatar have ranged 9.18-20.04 µg m^{-3}, 0.14-0.37 µg m^{-3}, 0.57-17.08 µg m^{-3}, and 4.08-7.89 µg m^{-3}, respectively. The mean annual concentrations of sulphur dioxide, nitric acid, hydrogen chloride and ammonia in the atmosphere of the remote site Terelj have ranged 0.38-1.56 µg m^{-3}, 0.01-0.06 µg m^{-3}, 0.18-6.53 µg m^{-3}, and 0.86-1.92 µg m^{-3}, respectively. Last four year's (2016-2020) of the mean annual concentrations of gaseous compounds in the atmosphere of Ulaanbaatar and Terelj are presented in Figure 4.

Figure 4. The mean annual concentrations of gaseous compounds, µg m^{-3}.

Nitrogen. The yearly changes of mean annual concentrations of nitrogen compounds at Terelj and Ulaanbaatar are presented in Figure 5. The result is showing that the NH_3 concentration was significantly decreased (~ 3 µg m^{-3} in Ulaanbaatar site and ~ 1 µg m^{-3} in Terelj site) in both sites.



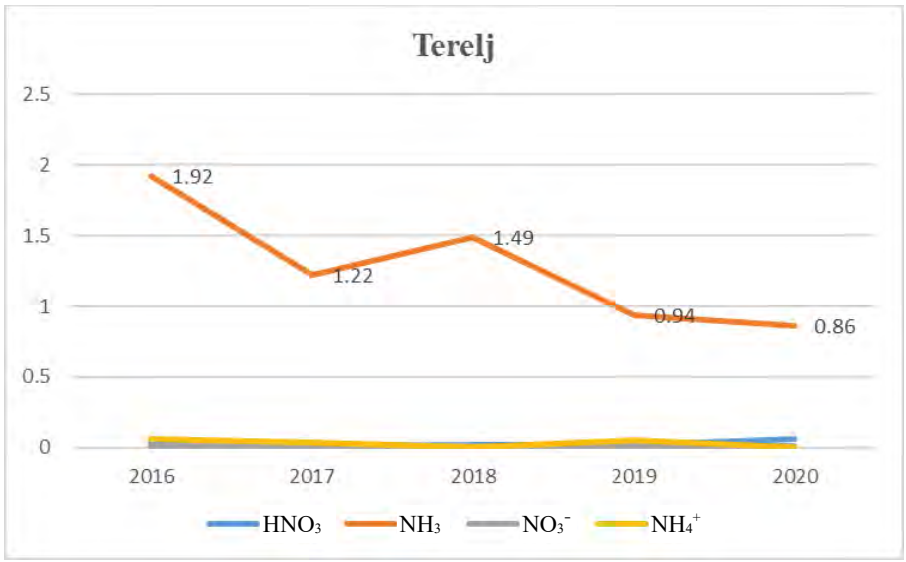


Figure 5. The mean annual concentrations of nitrogen compounds, µg m^{-3}

The average (2016-2020) of sulphur compounds in the atmosphere of Ulaanbaatar and Terelj are presented in Figure 6.

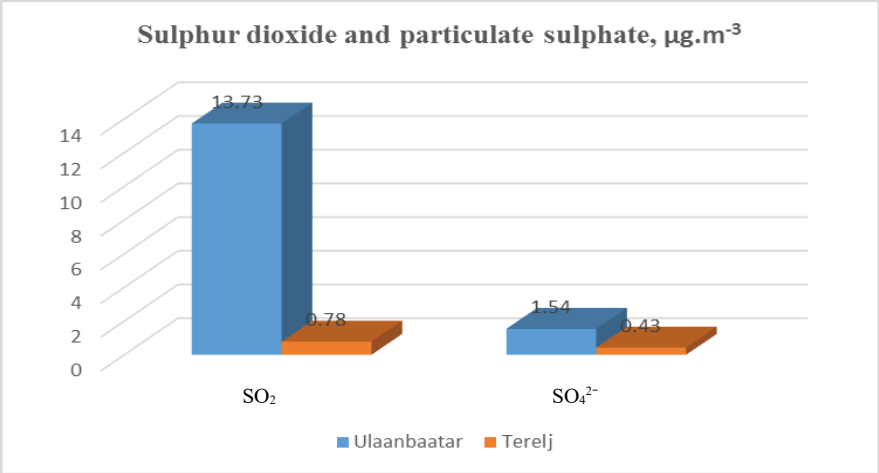


Figure 6. The average of sulphur dioxide and particulate sulphate in the atmosphere, µg m^{-3}, 2016-2020.

At the national level in Ulaanbaatar (urban site of EANET) have 6 automatic monitoring sites based on influencing emission sources and activities: roadside (UB02), urban (UB04, UB05), industrial (UB01, UB07) and background (UB08). The air pollution is a very serious problem in Ulaanbaatar in the cold season. There is a big diurnal, seasonal, annual variation defending air pollutant's characteristics and emission sources.

2.2 State of inland aquatic environment

Terelj River has been selected for the inland aquatic environment monitoring purpose because its water has quite low electric conductivity. The river starts at the western slope of Khentei mountain range and flows into the Tuul River. Terelj River water has very low mineralization with electric conductivity in the range of 43.8-50.9 µS·cm^{-1} and pH variations within 6.49-6.81. The average chemical composition of the Terelj River water for the period 2016-2020 is presented in Table 6.

Table 6 The mean annual concentration of the Terelj River, mg· l^{-1}

	pH	EC mS/m	Alk.	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}
2016	6.68	4.39	0.277	3.42	0.68	0.35	nd	1.45	0.57	6.55	0.82
2017	6.80	5.09	0.346	4.72	0.85	0.48	0.01	1.89	0.52	6.90	0.88
2018	6.81	4.38	0.279	3.52	0.83	0.30	0.001	1.90	0.43	5.72	0.70
2019	6.55	4.77	0.316	4.36	0.43	0.34	0.004	1.78	0.52	6.40	0.82
2020	6.49	5.02	0.335	4.21	0.66	0.33	0.005	2.18	0.49	7.29	0.82

The composition of the major ions in the Terelj River water is shown in Figure 7. The main dominated ion was the calcium (44%).

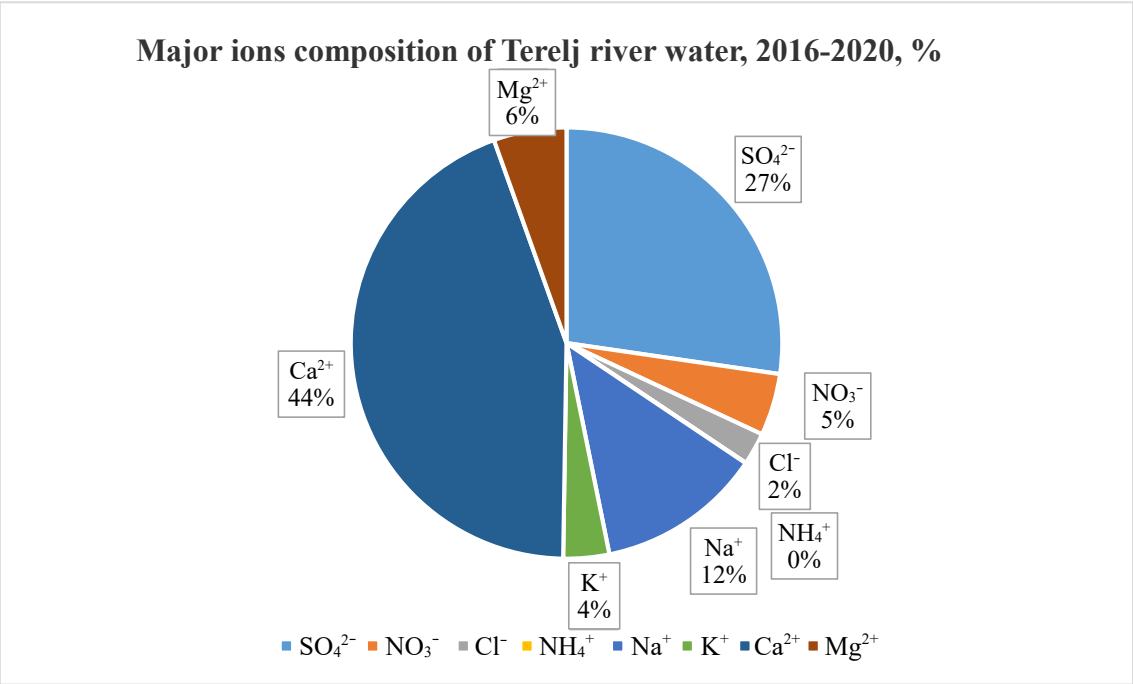


Figure 7. Major ion's ccomposition of Terelj River water, 2016-2020, %.

The dominant ion (Ca^{2+}, SO_4^{2-}, Na^+, Mg^{2+}) was Ca^{2+}(44%), followed by SO_4^{2-}(27%), Na^+(12%) and Mg^{2+}(6%) in the river water of Terelj.

3. Review of National Measures against Acid Deposition

- Due to the cold season (harsh winter) and equipment problems had a gap in the dataset.
- pH has decreased, sulphate to precipitation acidity was much higher than nitrate, and sodium, calcium and ammonium ions mostly have predominated among the cations in the precipitation water.
- The concentrations of SO_2 were highest during the winter (heating season) in Ulaanbaatar. The major sources are emission from coal burning for heating.

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National Assessment on Acid Deposition in Myanmar

1. Basic Information on National Monitoring Activities

1.1 Outline of activities on acid deposition and National Monitoring plan

Myanmar has participated Acid Deposition Monitoring Network in East Asia (EANET) activities from November 2005 to present. After Myanmar became participating country of EANET, the Department of Meteorology and Hydrology (DMH) is designated as National Center for EANET. DMH is conducting regular monitoring of acid deposition on rain water across Myanmar and wet and dry deposition in Kaba-aye, Yangon. Myanmar also started PM2.5 monitoring activities at Mandalay in 2015 which belong to the Environmental Conservation Department (ECD) and Yangon (Kaba-aye) in 2018 that belong to DMH, both of them are donated by the Asia Center for Air Pollution Research (ACAP) for Asia Pacific Clean Air Partnership (APCAP). Moreover, DMH is implementing the following activities and program cooperation with the UNEP-EANET secretary, and technical assistance of Network Center (ACAP):

- Developed National Monitoring Plan for EANET
- Developed Standard Operating Procedures(SOPs)
- Upgrading for the laboratory progress
- Capacity building of staffs in Myanmar on acid deposition
- Participation in the inter-laboratory comparison on wet deposition
- Public awareness activities in Myanmar
- Providing and sharing the dry and wet deposition, and PM2.5 data

In addition, Myanmar also participated regular meeting and training such as Intergovernmental meeting, Working Group meeting, Scientific Advisory Committee, and QA/QC activities of EANET and contribute the monitoring results of dry and wet deposition, research activities to EANET Science Bulletin, and National report of acid deposition and air pollution activities.

1.2 Monitoring Program in 2010-2019

The National Center (DMH) is conducted wet deposition monitoring by measuring pH, Electric Conductivity (EC) and the amount of precipitation after EANET participating country. Horiba pH/COND meter was used to measure the pH and EC in the collected rain water. In November 2011, Filter Pack Method System for dry deposition and Distilled Water Generator were installed at Yangon (Kaba-aye) with the support of ACAP. After installation the instruments, DMH has started analyze for wet and dry deposition by weekly in ion contents, such as Cation: ammonium (NH_4^+), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and, Anion: sulphate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-) and four gases, i.e., sulphur dioxide (SO_2), nitric acid (HNO_3), hydrogen chloride (HCl), and ammonia (NH3) as dry deposition. DMH has set up water purification system (RO-DI 30l(s) and RO-DI 15l(s) in March 2014, and Voltex Shakers in November 2014 with government budget. The air quality monitoring program using PM2.5 automatic monitor was carried out hourly monitoring at Mandalay (ECD office) started from April, 2015 and Yangon (Kaba-aye)

in March, 2018 to present. The results of all analysis data (pH, EC, Ions, PM2.5) are sent to ACAP by annually.

1.3 Monitoring Stations

In Myanmar, Yangon (Kaba-aye) station is monitoring wet and dry deposition and air pollution (PM2.5) with the installation of a wet sampler in June 2007, filter pack in November 2011 and PM2.5 in March 2018. Moreover, PM2.5 automatic air quality monitoring that belongs to Environmental Conservation Department (ECD) was installed at Mandalay in April 2015. Table 1 shows the geographical location and information of sites where as Figure 1 shows the spatial map of the monitoring stations.

Table 1 Geographical location and information of monitoring site in Myanmar

Monitoring Sites	Site Classification	Location			Measured Parameters
		Latitude	Longitude	Altitude (m)	
Yangon (Kaba-aye)	Urban	16˚51'53"N	96˚09'13"E	21.7	Wet and Dry Deposition PM2.5 monitoring
Mandalay (ECD)	Urban	21˚54'46"N	96˚03'51"E	70	PM2.5 monitoring

PM25 Monitoring at

Wet and Dry Deposition, and PM2.5 Monitoring at Yangon

Figure 1. Spatial location of EANET site in Myanmar.

1.4 Sampling and Measurements

Rainwater samples for wet deposition monitoring were collected daily by the wet only sampler and weekly composite analysis since 2008. Dry deposition monitoring sampling interval is biweekly and ion analysis since November, 2011. The amount of precipitation, pH and EC were measured by pH meter (pH/ COND meter Horiba) and analyzed ion contents by Ion Chromatograph following the technical manual for wet and dry deposition monitoring analysis adopted by EANET as shown in Table 2.

Table 2 Monitoring parameters and method for wet deposition and dry deposition

Monitoring Parameters		Method
Wet Deposition	**Dry Deposition**	
Electric Conductivity(EC)	-	Conductivity cell Method
pH	-	Glass electrode Method
Cl^-, NO_3^-, SO_4^{2-}	Cl^-, NO_3^-, SO_4^{2-}	Ion chromatography (preferably with suppressor)
NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}	NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_2, HNO_3, HCl, NH_3	Ion chromatography

2. Acid Deposition and Air Pollution in Myanmar and their Environmental Impacts

2.1 State of acid deposition and air pollution

2.1.1 State of wet deposition

2.1.1.1 pH and EC of wet deposition during 2010-2019

Acid deposition monitoring in Myanmar has been carried out according to the common methodologies specified in the "Technical Documents for wet deposition monitoring in East Asia". Precipitation samples are collected by Wet only Sampler on daily (rainy days) basis at Yangon (Kaba-Aye). Collected samples are measured and analyzed according to the technical manual at laboratory. The analysis results of annual minimum, maximum and mean values of pH, EC and total precipitation at Yangon (Kaba-aye) during the period 2010-2019 are shown in Table 3. All the data in this report are downloaded from the EANET data reports except meteorological data. Meteorological data are collected from the Department of Meteorology and Hydrology.

Table 3 Annual minimum, maximum and mean values of pH and EC on wet deposition at Yangon (Kaba-aye)

Station	Year	pH			EC (mS/m)			Annual Total Precipitation (mm)
		Min	Max	Mean	Min	Max	Mean	
Yangon (Kaba-aye)	2010	5.75	6.85	6.42	0.36	8.75	1.34	2280
	2011	6.20	7.09	6.46	0.32	5.28	0.68	3151
	2012	5.83	7.10	6.49	0.37	4.50	1.30	2570
	2013	6.06	6.99	6.45	0.42	8.30	0.81	2692
	2014	6.40	6.97	6.70	0.42	5.73	0.91	2872
	2015	6.41	7.09	6.66	0.60	9.79	1.46	2432
	2016	6.33	6.99	6.75	0.23	7.79	1.37	2180
	2017	6.50	6.97	6.69	0.23	2.99	0.50	2813
	2018	6.09	7.30	6.58	0.18	5.29	0.64	2940
	2019	5.50	7.00	6.53	0.40	5.00	0.91	2962

The annual average pH values and EC of Yangon (Kaba-aye) in 2010-2019 are shown in Figure 2. The annual range of pH value observed 6.42 – 6.75. The maximum pH value was detected in 2016 with the value of 6.75 and that of minimum was 6.42 in 2010. Among the study period, pH value was increased started from 2014 to 2019 while 2018 and 2019 was slightly decreased (Figure 2a). According to the record of pH in rain water at Yangon (Kaba-aye) site during 2010-2019, it can be conclude that the rain is clean and no acidity on that area. Figure 2b described the annual mean of EC in 2010-2019. It can be found that EC range was between 0.50 to 1.46 with the maximum values in 2015 and minimum in 2017. In the year 2010, 2012, 2015 and 2016 has high amount of EC values compare to the rest of the years.

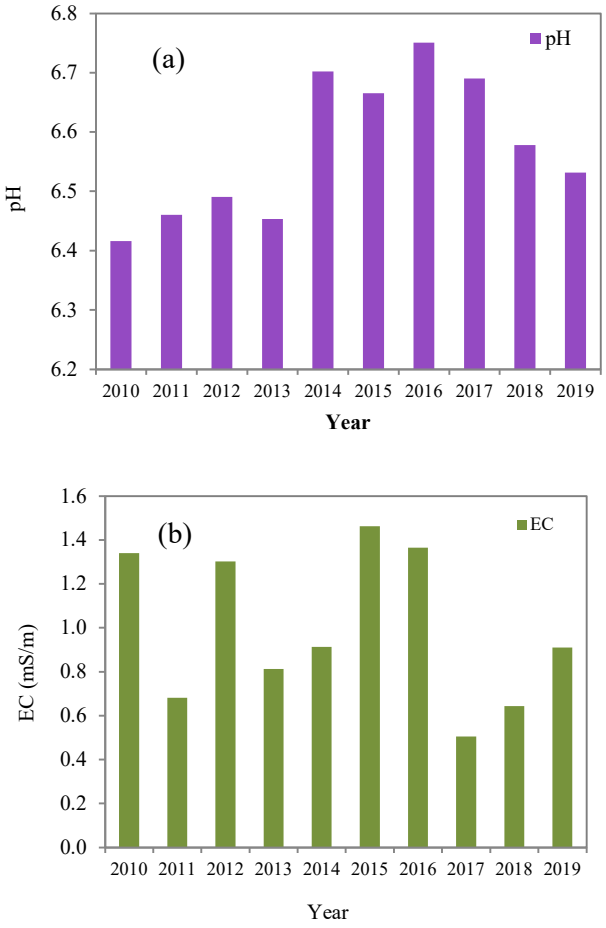

Figure 2. Annual average (a) pH and (b) EC of Yangon (Kaba-aye) during 2010-2019.

Monthly meteorological parameters such as temperature, relative humidity, wind speed, wind direction, precipitation amount and sunshine hours at Yangon (Kaba-Aye) site for the period 2010-2019 are presented in Table 4.

Table 4 Monthly mean meteorological data at Yangon (Kaba-Aye) in 2010-2019

Year	Month	Temperature (˚C) Mean		Relative humidity (%)	Wind speed (m/s)	Wind direction	Total Precipitation (mm)	Total Sunshine (hours)
		Max	Min	(Mean)	(Mean)			
2010	Jan	34.4	15.8	70.0	1.6	NE	0	240.8
	Feb	35.8	18.1	64.0	1.6	NE	0	255.3
	Mar	37.2	23.1	73.0	1.4	SE	0	231.3
	Apr	39.2	25.6	66.7	1.7	SW	0	290.6
	May	37.2	25.9	70.0	1.9	SW	308	211.7
	June	32.6	25.4	83.0	1.9	SW	529	67.8
	July	32.5	25.0	85.0	1.5	SE	367	96.8
	Aug	31.0	24.6	86.4	1.7	SE	467	63.4
	Sep	32.1	24.3	83.0	1.6	SW	402	97.2
	Oct	32.7	24.1	80.3	2.0	SE	367	156.0
	Nov	34.6	22.0	68.0	2.0	NE	7	264.6
	Dec	33.0	19.3	66.4	1.8	NE	33	255.0
2011	Jan	32.3	18.2	66.0	1.7	NE	48	247.8
	Feb	34.8	19.5	63.0	1.7	NE	0	260.1
	Mar	33.7	21.6	71.1	2.1	SE	127	210.3
	Apr	36.5	24.4	68.9	1.4	SE	5	238.8
	May	33.0	24.7	81.7	1.7	SW	412	123.0
	June	31.7	24.7	86.9	2.0	SW	567	54.6
	July	31.2	24.0	88.1	1.6	SW	574	80.0
	Aug	30.5	23.7	87.7	1.7	SW	615	51.8
	Sep	31.2	23.6	87.9	1.8	SW	538	64.5
	Oct	33.0	23.5	81.8	1.7	SE	178	162.1
	Nov	34.2	21.4	70.3	1.4	NE	0	266.9
	Dec	33.3	19.7	67.0	2.2	E	0	242.8
2012	Jan	33.5	17.1	63.2	1.7	NE	0	277.3
	Feb	36.0	18.8	70.0	1.5	SE	0	242.7
	Mar	36.9	21.9	69.6	1.3	SW	0	253.4
	Apr	37.9	24.4	65.8	1.6	SW	8	252.3
	May	34.8	24.5	76.6	1.3	SW	167	136.0
	June	31.7	23.6	85.9	1.6	SW	450	56.2
2012	July	31.1	22.8	87.9	1.3	SW	717	43.0
	Aug	30.2	22.4	89.5	1.4	SW	864	45.7
	Sep	32.0	22.6	84.5	1.4	SW	379	115.2
	Oct	33.8	22.7	80.0	1.6	NE	69	202.8
	Nov	33.9	22.1	78.4	2.1	SE	115	192.5
	Dec	32.6	17.3	97.9	2.4	NE	002	258.3
2013	Jan	32.7	15.8	70.8	2.2	NE	6	276.6
	Feb	36.6	19.2	70.0	2.4	SE	0	243.8
	Mar	37.1	20.0	67.6	2.1	SE	0	277.0
	Apr	38.6	21.9	66.9	2.1	SW	0	276.2
	May	35.5	22.4	78.0	2.8	SE	125	172.5
	June	31.4	22.1	88.6	2.1	SW	551	71.7
	July	30.4	24.0	89.2	2.0	SW	630	53.1
	Aug	30.9	24.2	89.9	2.2	SW	464	68.0
	Sep	31.2	23.9	89.2	1.7	SW	612	84.3
	Oct	32.6	23.7	81.2	1.9	SE	371	174.0
	Nov	34.1	22.9	75.0	2.8	NE	13	228.3
	Dec	30.9	17.6	73.8	1.8	NE	3	241.3

Table 4 Monthly mean meteorological data at Yangon (Kaba-Aye) in 2010-2019 (Continue)

Year	Month	Temperature (˚C) Mean		Relative humidity (%) (Mean)	Wind speed (m/s) (Mean)	Wind direction	Total Precipitation (mm)	Total Sunshine (hours)
2014	Jan	32.3	16.1	71.0	1.8	NE	0	283.1
	Feb	34.0	17.8	69.5	1.4	NE	0	254.4
	Mar	37.4	20.0	66.5	1.6	SE	0	288.6
	Apr	38.1	23.8	70.6	1.3	SW	0	220.5
	May	35.9	23.7	75.0	1.5	SW	0	243.7
	June	32.1	22.8	87.3	1.4	SW	701	48.6
	July	31.0	21.8	90.6	1.6	SW	818	26.5
	Aug	31.1	21.3	89.0	1.6	SW	575	52.7
	Sep	31.9	21.0	83.0	1.4	SW	197	79.1
	Oct	33.6	22.6	76.3	1.7	SE	224	194.5
	Nov	33.4	21.9	77.2	0.8	SE	300	203.0
	Dec	33.8	19.5	66.0	0.9	NE	26	259.6
2015	Jan	32.7	18.9	65.0	2.2	SE	0	232.7
	Feb	34.9	18.8	66.3	1.8	SE&SW	0	234.5
	Mar	37.6	21.8	63.6	2.4	SE	9	262.9
	Apr	38.1	23.8	64.8	2.2	SW	40	271.2
	May	36.1	25.0	72.7	2.0	SW	185	199.0
	June	32.5	24.6	84.4	1.7	SW	580	88.7
	July	31.6	24.3	88.5	2.4	SW	726	76.9
	Aug	31.1	24.4	89.2	1.7	SW	408	57.2
	Sep	32.1	24.0	86.9	2.1	SW	329	108.5
	Oct	32.4	23.4	83.6	3.1	SE	355	134.4
	Nov	34.0	22.0	75.6	2.7	NE	69	245.0
	Dec	33.3	19.4	71.7	2.4	NE	0	253.1
2016	Jan	31.8	15.7	67.1	2.7	NE	23	249.6
	Feb	34.3	18.8	70.6	2.1	SE	0	239.2
	Mar	36.6	22.1	69.7	1.6	SW & SE	0	226.2
	Apr	38.5	24.1	68.2	2.1	SW	0	229.3
	May	37.2	24.2	71.6	2.3	SW	270	145.5
	June	31.6	23.2	86.0	2.1	SW	379	51.8
	July	32.0	22.9	87.8	2.1	SW	539	45.8
	Aug	31.3	22.5	116.4	2.4	SW	526	66.4
	Sep	32.3	23.9	87.0	2.4	SE	397	79.4
	Oct	33.7	24.1	86.0	2.3	SE	227	128.6
	Nov	33.4	22.8	74.4	2.7	SE	1	230.2
	Dec	33.7	21.5	72.5	2.3	NE	0	219.4
2017	Jan	33.0	19.9	66.7	2.4	NE	1	228.7
	Feb	34.6	19.5	64.7	2.0	NE & SE	0	247.6
	Mar	36.7	21.6	64.1	1.7	SW	0	283.5
	Apr	36.1	24.3	67.3	1.7	SW	81	216.5
	May	35.1	25.2	78.5	2.0	SW	449	142.5
	June	31.4	24.0	85.0	2.5	SW	650	60.4
	July	30.0	23.2	92.9	1.9	SW	802	35.6
	Aug	30.7	23.0	88.8	1.7	SW	382	42.6
	Sep	32.2	23.1	86.3	2.0	SE	401	109.7
	Oct	31.8	22.2	86.5	2.2	SE	460	143.4
	Nov	33.0	21.7	75.7	1.8	NE	125	202.6
	Dec	31.9	18.1	67.8	2.7	NE	0	256.2

Table 4 Monthly mean meteorological data at Yangon (Kaba-Aye) in 2010-2019 (Continue)

Year	Month	Temperature (˚C) Mean		Relative humidity (%) (Mean)	Wind speed (m/s) (Mean)	Wind direction	Total Precipitation (mm)	Total Sunshine (hours)
2018	Jan	32.5	17.3	68.3	1.9	SE	0	214.0
	Feb	34.2	17.4	62.2	1.6	NE	0	236.3
	Mar	36.4	20.4	71.8	1.7	SE	0	232.7
	Apr	37.6	22.8	61.9	1.6	SE	42	241.4
	May	35.4	23.2	69.3	2.2	SE	229	145.1
	June	30.9	21.6	86.2	2.4	SW	627	44.1
	July	30.1	21.4	91.0	2.0	SW	796	21.9
	Aug	30.1	21.0	88.7	2.3	SW	579	32.2
	Sep	31.8	21.2	87.7	2.4	SE	472	105.4
	Oct	32.9	20.6	79.5	1.9	SE	229	161.4
	Nov	33.7	19.1	72.2	2.2	SE	66	237.2
	Dec	33.2	17.9	72.2	2.1	NE	61	223.6
2019	Jan	32.3	16.4	68.9	1.93	NE/SE	50	259.2
	Feb	35.7	17.5	66.6	1.68	NE/SE	0	250.8
	Mar	36.9	19.6	67.5	1.78	SE/SW	0	222.7
	Apr	40.0	22.2	63.3	1.69	SE/NE	0	257.8
	May	36.1	25.3	75.9	1.78	SW	0	114.2
	June	31.8	24.8	86.9	1.92	SW	551	53.9
	July	30.7	23.7	90.7	1.85	SW	630	33.6
	Aug	30.1	24.3	92.4	1.93	SW	782	35.1
	Sep	31.9	24.0	88.2	2.07	SE/SW	450	106.8
	Oct	34.3	24.3	80.0	1.48	SE/SW/NE	183	191.8
	Nov	33.3	22.9	79.8	1.76	SE/NE	167	206.1
	Dec	32.4	17.3	70.6	2.00	SE	0	260.9

2.1.1.2 Concentration of major ions of wet deposition in 2010-2019

The monthly average variations of major ions of wet deposition during 2010-2019 are shown in Figure 3. The ions concentration data of wet deposition in February was not available in 2010-2019. The data results showed that the higher concentration rage of both anions and cations observed from November to May (dry period) with slightly highest in March (Figure 3.a and b). The rest of the months from June to October (wet period) were observed lower concentration in all species. NO_3^- was the highest concentration during October to April while Cl^- was the highest in May to September among the anions (SO_4^{2-}, NO_3^-, Cl^-). SO_4^{2-} was observed the lowest concentration. On the other hand, Ca^{2+} was the higher concentration among the cations (NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}). The concentrations in dry period of all species were approximately 2 times higher than that of wet period.

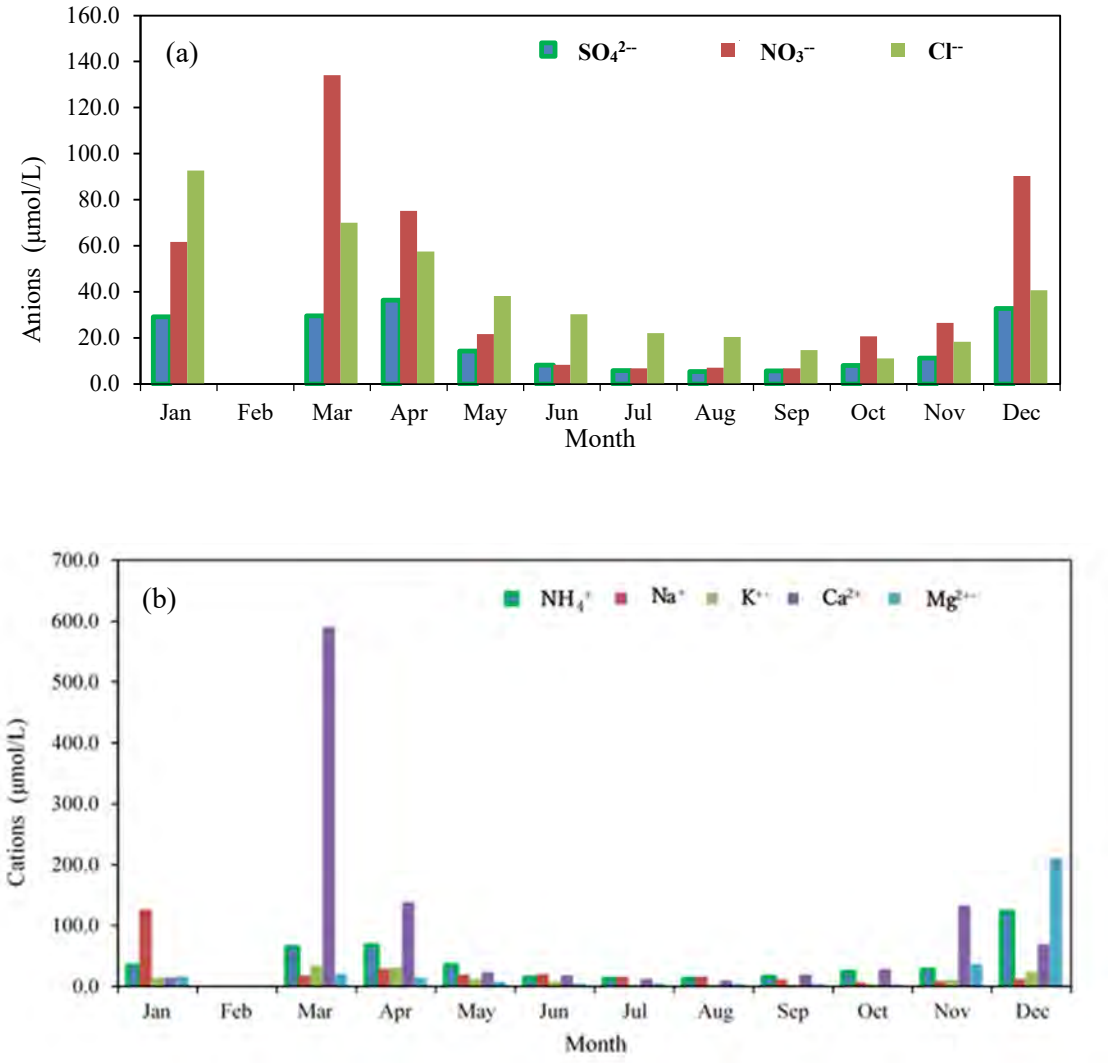

Figure 3. Monthly variations of ions concentration (a) anions, and (b) cations at Yangon (Kaba-aye).

Table 5 describes the analysis results of annual mean of ions concentration (µmol/L) while Figure 4 represents the annual average of ions concentration during 2010-2019 at Yangon (Kaba-aye).

Table 5 Annual average ion concentration for wet deposition at Yangon (Kaba-aye) in 2010-2019

Years	NH_4^+ µmol/l	Na^+ µmol/l	K^+ µmol/l	Ca^{2+} µmol/l	Mg^{2+} µmol/l	SO_4^{2-} µmol/l	NO_3^- µmol/l	Cl^- µmol/l
2010	14.59	12.85	2.07	6.37	1.80	4.52	4.96	13.17
2011	14.88	14.98	1.66	6.89	3.02	6.63	6.30	15.76
2012	17.75	22.07	6.78	7.79	6.56	7.48	8.31	26.58
2013	17.03	15.83	2.66	1.07	12.31	7.96	6.72	27.08
2014	16.58	17.26	4.69	14.15	3.41	4.55	4.80	19.51
2015	22.31	8.77	13.25	88.70	5.87	4.62	8.25	34.39
2016	19.49	4.23	2.11	14.28	1.44	5.37	7.66	6.45
2017	13.57	15.00	10.44	10.50	3.46	11.57	18.29	35.23
2018	19.51	21.87	4.38	16.61	4.72	8.09	9.98	21.82
2019	16.99	18.30	7.01	14.16	4.00	8.77	22.1	20.80

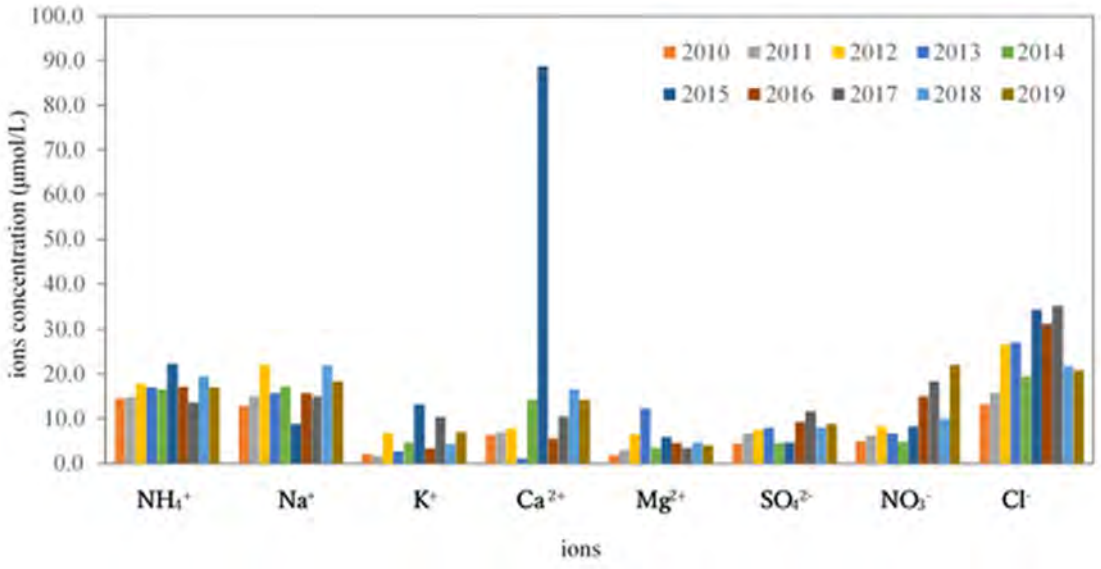

Figure 4. Annual average of ions concentrations during 2010-2019 at Yangon (Kaba-aye).

From the Figure 4**,** NH_4^+ was the highest concentration followed by Na^+ among the cat ions of wet deposition in each of the year. On the other hand, Cl^- was the most abundant and SO_4^{2-} was the least abundant among the anions. The annual variation of all the acidic ions concentration were not significant fluctuations except Ca_2^+ ion in 2015 similar with NH_4^+ and K^+ which were the maximum concentration during 2010-2019. The rest of the species are remained relatively stable. The simple linear regression model was used to identify the trend of all species. Figure 5 shows the trends of yearly average concentration of all species at Yangon (Kaba-aye).

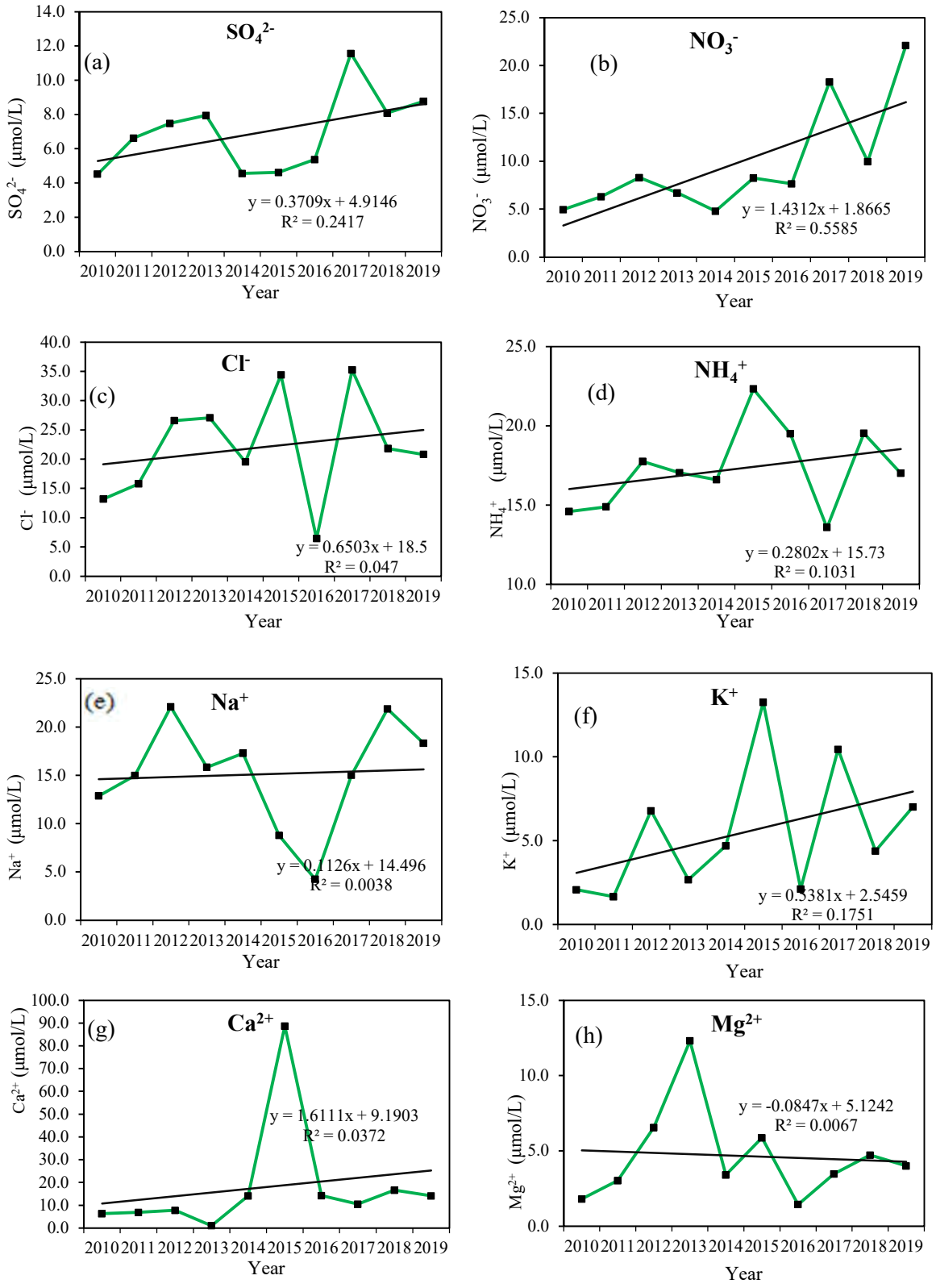

Figure 5. Trend of yearly average ions concentration for wet deposition at Yangon (Kaba-aye) during 2010-2019.

The concentrations of all the ions (SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}) (Figure 5. a-h) showed

increasing trend except Mg^{2+} (Figure 5.h) that was slightly decreased. NO_3^- (Figure 5.b) and K^+ (Figure 5.f) were observed significant increased whereas Na^+ (Figure 5.e) was no trend. All the ions concentrations are fluctuation with increased and decreased during the study period. Anions of SO_4^{2-} and Cl^- were observed maximum concentration with 11.57 µmol/l, and 35.23 µmol/l in the year 2017 while NO_3^- was highest in 2019. Among the cations, NH_4^+, K^+, Ca^{2+} were observed maximum concentration in 2015 with 22.31 µmol/l, 13.25 µmol/l, and 88.70 µmol/l, respectively. Moreover, the highest concentration of Na^+ with 22.07 µmol/l in 2012 and Mg^{2+} with 12.31 µmol/l in 2013 were observed.

2.1.2 State of dry deposition

Four gases such as SO_2, HNO_3, HCl and NH_3 and eight major ions, namely, Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+} are considered to monitor dry deposition for acid deposition. The dry deposition data are available from 2012 to 2019 as the monitoring was started end of 2011.

The monthly average variations of gaseous and major ions of dry deposition during 2012-2019 are shown in Figure 6. The higher concentration rage of gaseous (SO_2, HNO_3, HCl and NH_3) (Figure 6.a), anions (Cl^-, NO_3^-, SO_4^{2-}) (Figure 6.b), and cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}) (Figure 6.c) were observed from November to May (dry period). The rest of the months from June to October (wet period) were observed lower concentration in all gaseous and ions. The concentrations in dry period of all gaseous and ions were approximately 2 times higher than that of wet period that is similar to wet deposition of that area. Among the gaseous, NH_3 has highest concentration in all the months, followed by SO_2, HNO_3 and HCl. On the other hand, SO_4^{2-} has highest concentration in all the months compared to other anions species except in December. For the cations, the maximum concentration in Ca^{2+} was observed in the study site.

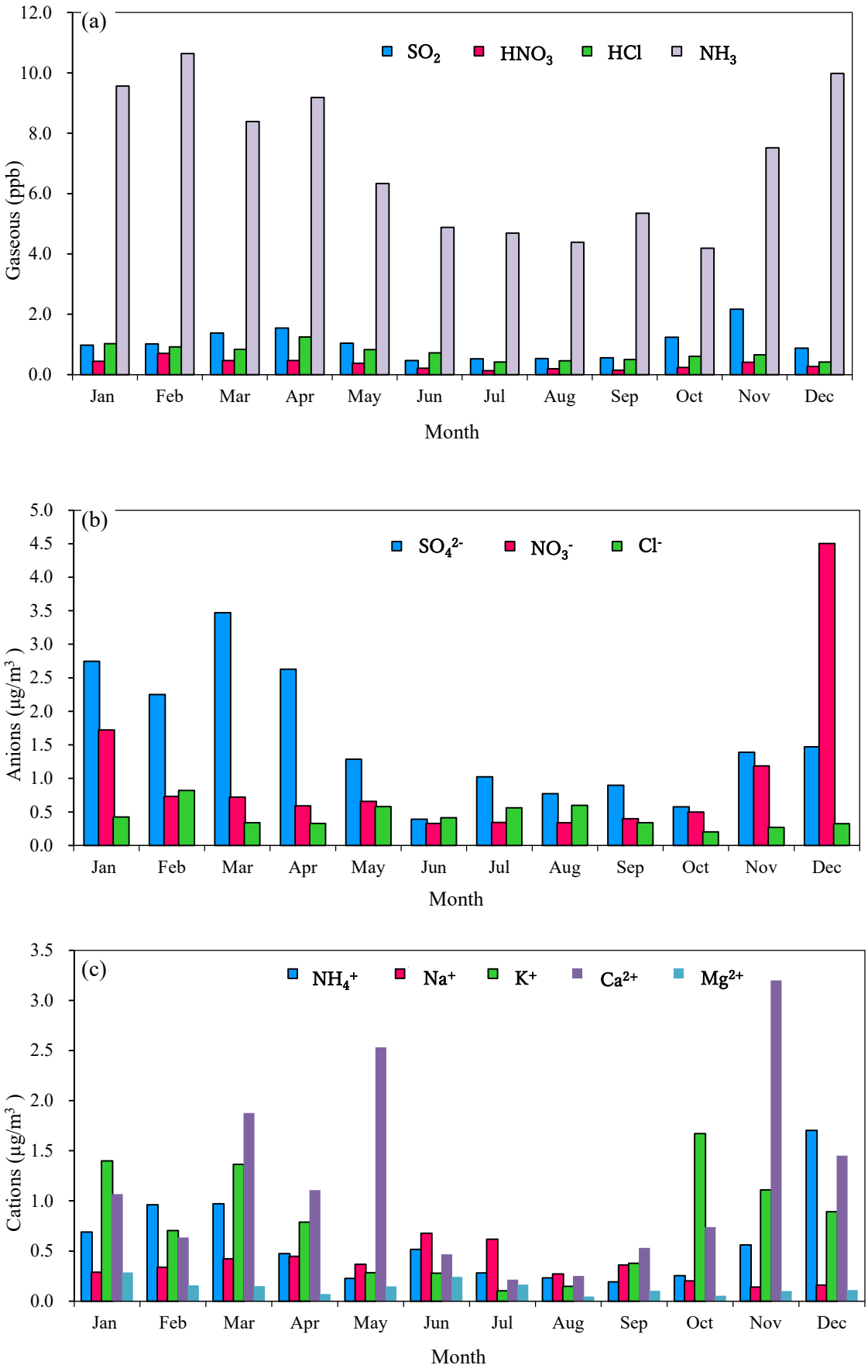

Figure 6. Monthly variations of (a) gaseous (b) anions, and (c) cations at Yangon (Kaba-aye).

Table 6 describes the analysis results of annual average of gaseous (ppb) and ions concentration (μg/m^3) while Figure 7 represents the temporal variations of gaseous and ions concentration of dry deposition during 2012-2019 at Yangon (Kaba-aye).

Table 6 Annual average of gaseous and ion concentration for dry deposition at Yangon (Kaba-aye) in 2012-2019

Year	Gaseous (ppb)				Anions (μg/m^3)				Cations (μg/m^3)			
	SO_2	HNO_3	HCl	NH_3	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}
2012	2.88	0.43	1.54	10.25	3.59	0.92	0.56	0.38	0.74	0.76	1.02	0.13
2013	1.30	0.30	0.60	6.20	1.40	0.54	0.21	0.30	0.21	0.24	0.29	0.04
2014	1.20	0.20	0.70	8.90	1.56	0.33	0.27	0.50	0.34	0.55	0.51	0.09
2015	0.50	0.20	0.70	7.60	0.90	0.44	0.63	0.45	0.12	0.94	3.11	0.15
2016	0.40	0.20	0.20	7.14	0.54	0.48	0.57	0.37	0.31	0.40	1.69	0.20
2017	0.50	0.20	0.40	5.80	1.70	1.65	0.13	0.80	0.19	0.47	0.40	0.04
2018	0.70	0.30	0.50	2.00	1.52	0.82	0.52	0.33	0.58	0.4	0.24	0.06
2019	0.80	0.30	0.60	2.10	1.51	0.60	0.23	0.40	0.27	1.4	0.27	0.05

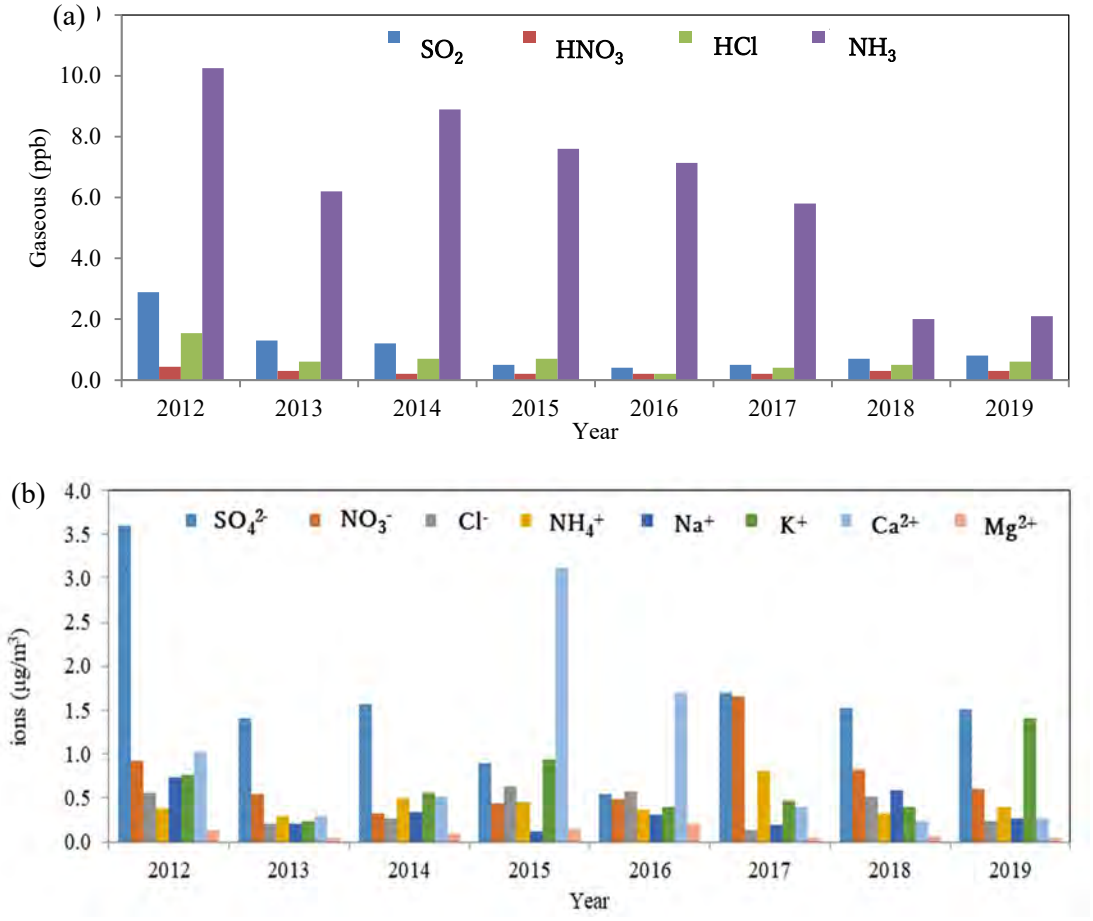

Figure 7. Temporal variations of (a) gaseous, and (b) ions concentration of dry deposition at Yangon (Kaba-aye).

From the Figure 7a, NH_3 has highest concentration in all years, followed by SO_2, HCl, HNO_3. On the other hand, SO_4^{2-} has highest concentration followed by Ca^{2+}, NO_3^-, K^+, NH_4^+, Na^+, Cl^-, and Mg^{2+} during study period. Most of the species tend to decrease in all years although $Ca2^+$ in 2015 and SO_4^{2-}, NO_3^-, and NH_4^+ in 2017 likely to increase (Figure 7.b). Linear regression model was used to identify the annual trend of all the gaseous and ions of dry deposition during 2012-2019. Figure 8 represents the trend of yearly average concentration of all gaseous and ions at Yangon (Kaba-aye).

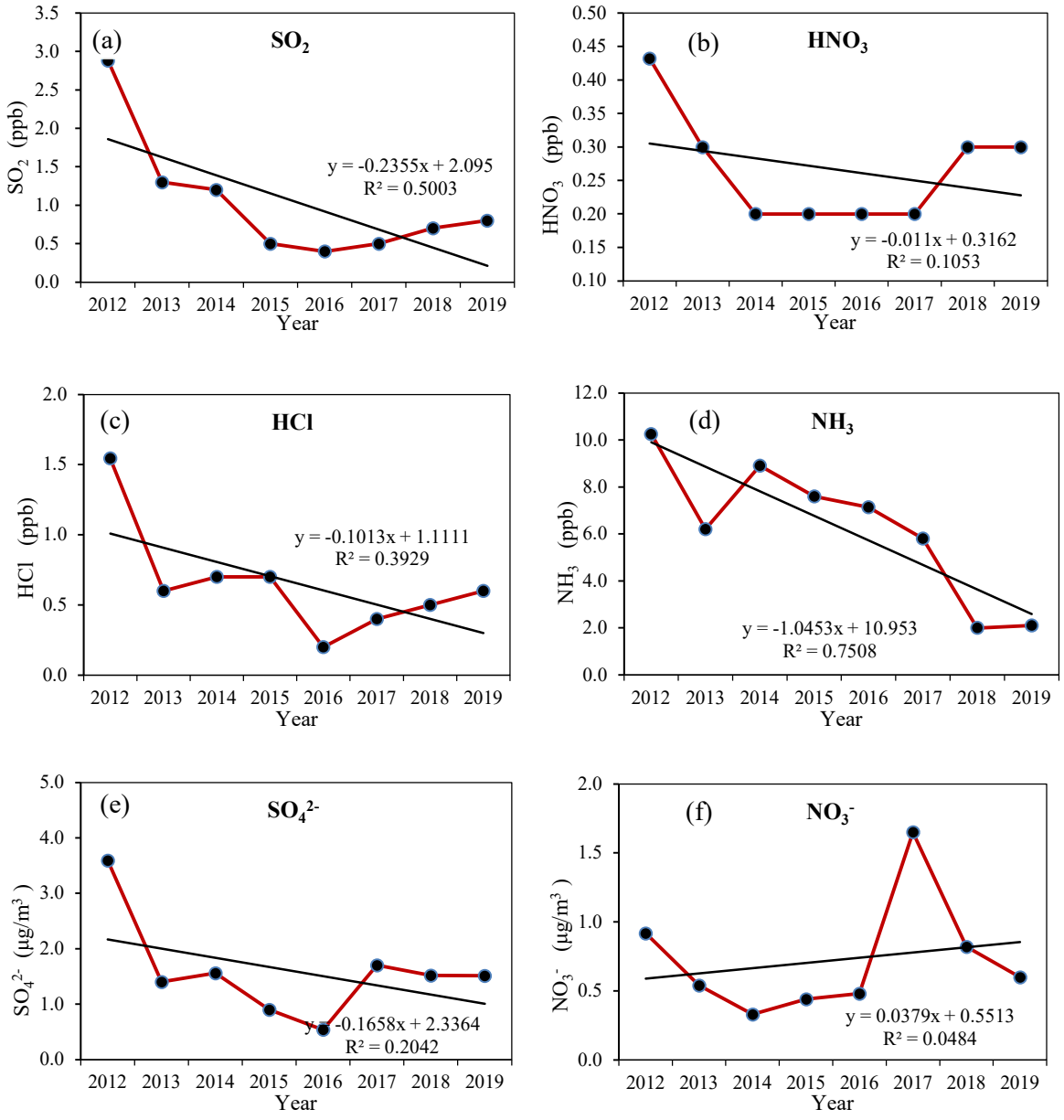

Figure 8. Annual trends of all gaseous and ions concentration for dry deposition at Yangon (Kaba-aye).

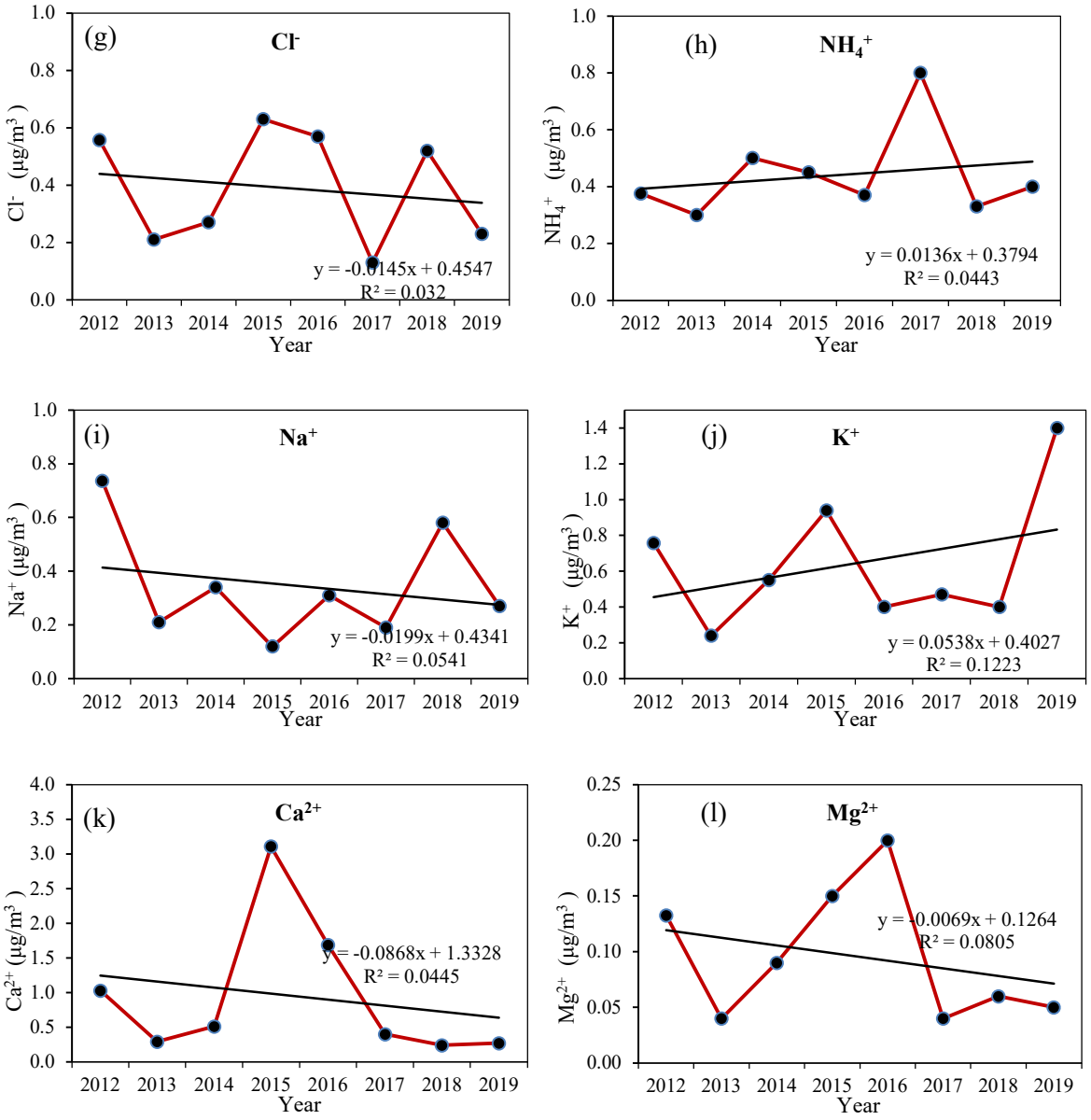

Figure 8. Annual trends of all gaseous and ions concentration for dry deposition at Yangon (Kaba-aye). (Continue)

The trend of all gaseous SO_2, HCl and NH_3 (Figure 8. a, c, and d) showed significant decreasing and insignificant in HNO_3 (Figure 8.b). In the ions species, SO_4^{2-}, Cl^-, Na^+, Ca^{2+} and Mg^{2+} (Figure 8. e, g, i, k, and l) observed decreasing trend while the rest of the ions NO_3^-, NH_4^+, and K^+ (Figure 8. f, h, and j) showed increasing trend. All the gaseous and ions are likely to increase in the last two years, 2018 and 2019.

2.1.3 State of $PM_{2.5}$ concentration

Daily average concentration of $PM_{2.5}$ with rainfall compared with the daily average of World Health Organization (WHO) standard during April 2018 to December 2019 at Yangon (Kaba-aye) is shown in Figure 9. The air quality is better condition during the rainy season (May to October). As long as rain start, $PM_{2.5}$ concentration tends to decrease in the month of May and goes down to the below

standard line. When rain stop, $PM_{2.5}$ concentration started increasing gradually from November, peak in January and February, after that, gradually decreased in March. The increasing of $PM_{2.5}$ concentration in dry period observed above the daily average (25 µg/m^3) of WHO standard. Table 7 describes the annual average, maximum and minimum value of $PM_{2.5}$ concentration at Yangon (Kaba-aye) and Mandalay. According to the monitoring results of annual average in both Yangon and Mandalay found that $PM_{2.5}$ concentration was higher than annual average (10 µg/m^3) of WHO standard. Thus, it can be conclude that the air quality in both area was exceeded the maximum permissible levels of WHO standard and it should be aware for human health and environmental problem.

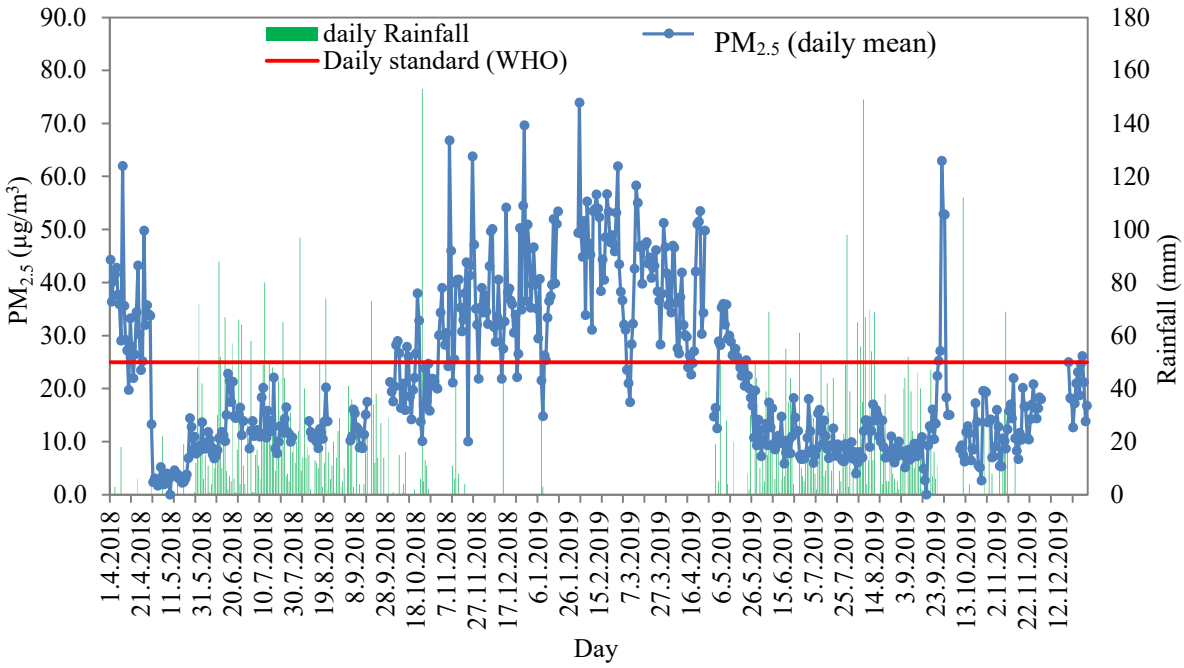

Figure 9. Temporal variation of daily average concentration of $PM_{2.5}$ at Yangon (Kaba-aye).

Table 7 Mean, Maximum and Minimum values of $PM_{2.5}$ at Yangon (Kaba-aye) and Mandalay

$PM_{2.5}$ µg/ m^3						
Year	Yangon			Mandalay		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
2016	-	-	-	33	135	3
2017	-	-	-	37	161	<1
2018	24	70	<1	16	43	2
2019	26	72	5	41	107	2

2.2 Overall analysis

The analysis results of EANET monitoring site in Myanmar, among the observed data (rain water sample) from Yangon (Kaba-Aye) urban site, most of the measured mean pH values throughout the year were between 6.42 and 6.75, which is the little lower than (0.1) the desirable range for drinking water from national drinking water quality standard (6.5 -8.5) and maximum permissible range of WHO standard (6.5 -9.2). Hence, it can be generally concluded that acid deposition is not significant in Myanmar.

Regarding the value of EC (Table 3), the maximum of 9.79 mS/m was recorded on March 2015 but it is under the acceptable level. It was the pre-monsoon season in 2015, and there could be some contaminants in that rain water sample. From the data recorded in 2010 to 2019, the overall analysis describes the average concentrations of pH and EC are remained within the acceptable level.

Both wet and dry deposition of all gaseous and ions indicated the higher concentration range in dry period and lowest in wet period. The concentration range in dry period was denoted more or less double of wet period. Similarly, the increasing and decreasing trend of both wet and dry deposition were observed. NH_3 and SO_4^{2-} were observed the maximum concentration among the gasous and ions. The higher NH_3 emission reflect higher concentration of NO_3^- as NH_3 reacts with first H_2SO_4 then with HNO_3 and became SO_4^{2-} and NO_3^-in the air. Moreover, the higher SO_4^{2-} and NO_3^-which could be related with mobile sources for the particulates formation in study site. The higher deposition of SO_4^{2-}, NO_3^- and NH_4^+ at study site could be contributed potential acidification and eutrophication of ecosystems. Similarly, the second higher concentration of SO_2 could be impact on buildings and monuments as well as deposition of base cations could be important for nutrient cycling in soils and ecosystems in the study area.
Based on the $PM_{2.5}$ monitoring results of Mandalay and Yangon proved that, the $PM_{2.5}$ concentration was over the daily standard and annual standard of WHO especially in the dry period (November to April). According to the Air Quality Index (AQI), the situation of air quality in both Mandalay and Yangon was facing “moderate” to “unhealthy for sensitive groups” level that might be impacts on the human health and environmental issue.

3. Review of National Measure against Acid Deposition

Myanmar has been adopted environmental laws and institutional framework for environmental and air quality management in Myanmar, such as, Environmental Conservation Law, Environmental Conservation Rules, National Environmental Policy, Environmental Quality (Emission) Guideline, Myanmar Climate Change Strategy, Myanmar National Waste Strategic and Master Plan, however there is still no national air quality standard, law and regulation in Myanmar. The relevant departments and organizations are closely cooperation and working together to development strategy and action plan for air quality management in Myanmar including monitoring, source inventory, open burning control, emission control as well as transboundary pollution control and public awareness for achieving sustainable development and mainstreaming of environmental protection and management.

4. Conclusion

Myanmar has joined EANET activities since the end of the year 2005 as National Focal with the technical cooperation of ACAP-Network Center for EANET, and conducting EANET activities, including regular monitoring of rain water, wet and dry deposition, and air quality monitoring ($PM_{2.5}$) in Yangon (Kaba-aye). All the monitoring results are contributed to Network Center of EANET and participating countries as well as the relevant governmental organization. The great progress has been made in achieving public awareness workshops on air pollution including acid deposition on 2007, 2013, and recent year 2020 by participation of multi-stakeholders, policy makers, education sector, NGOs, and general public. Besides, brochures on acid deposition problems in Myanmar

language have been distributed to schools, universities, libraries, governmental departments and NGOs, and other relevant and interested parties. In the future, Myanmar will be conducted regular activities of EANET, expanding monitoring network, enhancing capacity building, research activities and public awareness in the area of acid deposition and ambient air quality.

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National Assessment Report in the Philippines

Chapter 1. Basic Information on National Monitoring Activities

1.1. Outline of activities on acid deposition and National Monitoring Plan

The Acid Deposition Monitoring Network in East Asia (EANET) was created in 2001 aiming to create a common understanding of the state of acid deposition problems in East Asia, provide useful inputs for decision-making at national and regional levels to prevent or reduce adverse impacts on the environment and promote cooperation on the issue of acid deposition among its Participating Countries.

The Philippines through the Department of Environment and Natural Resources - Environmental Management Bureau (DENR- EMB), the National Center for EANET, has been participating in the various activities of the EANET which include (1) annual implementation of National Monitoring Plan for wet deposition and dry deposition, soil and vegetation, inland aquatic environment and catchment-scale, (2) participation in the following activities implemented by the Asia Center for Air Pollution Research (ACAP), the Network Center for the EANET such as inter-laboratory comparison exercises, technical support and capacity building activities, promotion of research and studies related to acid deposition issues, promotion of public awareness, and cooperation and information exchange in national and regional levels.

The EMB-DENR annually submits the monitoring data to the Network Center, the Asia Center for Air Pollution Research (ACAP), where the compilation, evaluation, storage and provision of data, promotion of quality assurance and quality control (QA/QC) activities are implemented.

1.2. Monitoring Program

All EANET monitoring sites in the Philippines were established with the assistance of experts from the formerly Acid Deposition and Oxidant Research Center (ADORC), now the ACAP. Table 1 shows the EANET monitoring sites, intervals, and parameters while Figure 1.1 shows the location map of EANET sites and Figure 1.2 shows the photographs of the monitoring stations.

In reference to the Quality Assurance/Quality Control (QA/QC) Guidebook for Acid Deposition Monitoring Network in East Asia – 2016, the National Monitoring Plan (NMP) had been prepared and is updated annually for the implementation of the annual national monitoring activities. Monitoring activities have been conducted using QA/QA protocols.

The EMB-CO Environmental Research and Laboratory Services Division conducts the monitoring activities on wet deposition, dry deposition, inland aquatic environment and catchment-scale that are located at the urban and rural sites while the EMB-Cordillera Administrative Region (CAR) conducts the monitoring activities located at the remote sites. The meteorological data respective to the deposition monitoring sites are being provided by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) of the Department of Science and Technology

(DOST). Recently, national air pollution monitoring activities were integrated in the EANET NMP.

Table 1 EANET monitoring components, sites, intervals, and parameters

Component	Monitoring Site/s	Latitude	Longitude	Monitoring Interval	Measured Parameters
Dry and Wet Deposition	Urban site: Metro Manila (MM) at Manila Observatory, Ateneo de Manila University Campus, Quezon City	14°38' N	121°04' E	Weekly	Dry Deposition: • SO_2 concentration converted from SO_4^{2-} concentration; • NO_2 concentration converted from NO_3^- concentration; • HCl concentration converted from Cl^- concentration; • NH3 concentration converted from NH_4^+ concentration; and • Na^+, K^+, Ca^{2+}, Mg^{2+}) Wet Deposition: • pH; Electric Conductivity (EC); • Concentration of cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}); and • Concentration of anions (SO_4^{2-}, NO_3^-, Cl^-)
	Rural site: Los Baños (LB) at PAGASA Agromet Station, UP Los Baños, College, Laguna	14°09' N	121°15' E		
	Remote site: Mt. Sto. Tomas (MST) at PAGASA Baguio Radar Station, Mt. Sto. Tomas, Tuba, Benguet	16°25' N	120°36' E		
Catchment-scale	La Mesa Watershed in Lagro, Quezon City			Monthly	• pH; Electric Conductivity (EC); Alkalinity • Concentration of cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}); and • Concentration of anions (SO_4^{2-}, NO_3^-, Cl^-)
Inland Aquatic Environment	Rural site: Pandin Lake in San Pablo, Laguna	14°7' N	121°22' E	Quarterly	• pH; Electric Conductivity (EC); Alkalinity • Concentration of cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}); and • Concentration of anions (SO_4^{2-}, NO_3^-, Cl^-)
	Remote site: Ambulalakao Lake in Kabayan, Benguet	16°66' N	120°89' E		
$PM_{2.5}$ Monitoring	MM Site at Ateneo de Manila University Campus, Quezon City	14°38' N	121°04' E	Continuous (Weekly downloading of data)	• $PM_{2.5}$
Soil and Vegetation	Urban site: La Mesa Watershed in Lagro, Quezon City			Every 3 - 5 years (No monitoring data in 2015-2019)	Soil Monitoring • Moisture content; pH (H2O) and pH (KCl); • Exchangeable base cations (Na^+, K^+, Ca^{2+}, Mg^{2+}); • Exchangeable acidity; • Effective cation exchangeable capacity (ECEC); • Carbonate content (when pH (H2O) > 7); Vegetation Monitoring: • General description of the forest: Description of the tree (name of species, diameter at breast height and height of tree) and understory vegetation survey • Survey of tree decline: Observation of tree decline, photographic record of tree decline, and estimation of decline causes
	Rural site: Mt. Makiling Forest Reserve in UP Los Baños College, Laguna				
	Rural site: UP Quezon-Laguna Land Grant in Siniloan, Quezon				
	Remote site: Boneco Long Term Ecological Research Site in Itogon, Benguet				

1.3 Monitoring Sites/Stations

The established monitoring sites are shown in Figure 1.1 and in Figure 1.2 are photographs of the monitoring stations

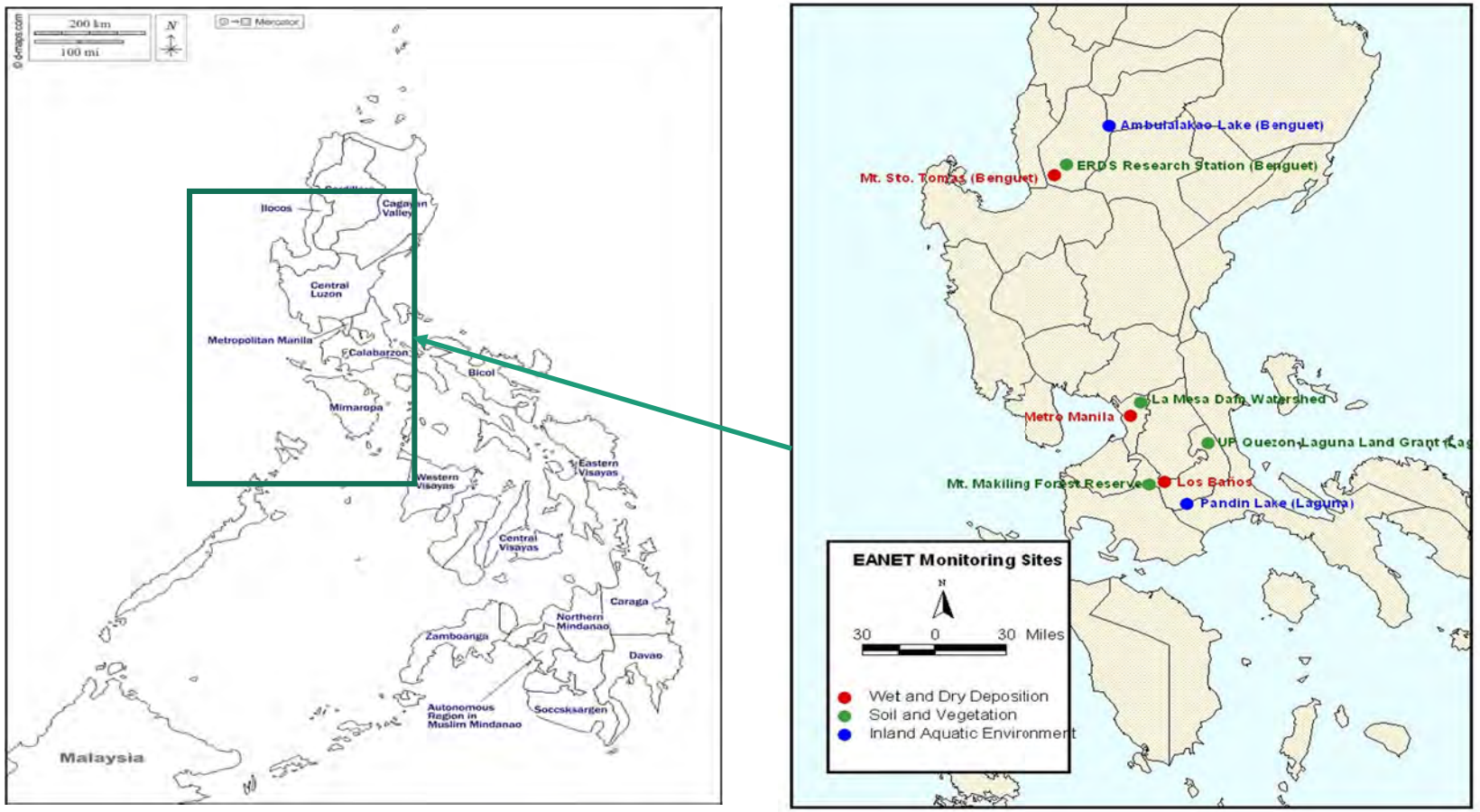


Figure 1.1. EANET monitoring sites (Catchment–scale study site is located in La Mesa Watershed).

Figure 1.2. Photographs of the monitoring stations and activities.

1.4 Sampling and Measurements

Wet and dry deposition monitoring are implemented to measure concentrations and fluxes of acidic substances deposited to the ground, while soil and vegetation and inland aquatic environment monitoring are carried out to assess the adverse impacts on terrestrial and aquatic ecosystems. Catchment-scale is an integrated monitoring activity which purpose is to evaluate both the quantitative and qualitative effects of acid deposition on ecosystems.

1.4.1 Wet and Dry Deposition Monitoring

Rainwater samples for Wet Deposition (WD) monitoring had been collected weekly using automatic rainwater sampler (Ogasawara Keiki US-330) installed at the sites. Measurements for the required parameters had been done in reference to the Technical Manuals on WD and on DD published by the EANET.

During 2015-2019 monitoring period, data generated was not complete for the sensors of the rainwater samplers had all worn out in 2017. There were no immediate replacements for there had been no local suppliers for such sensor and also for the whole rainwater sampler. Monitoring activities continued then and the annual data were submitted stating the condition of the sampler. However, those data were not acceptable as WD data. In early 2019, an ACAP Team conducted a Technical Mission in Manila bringing with them sensors. One was used as replacement for the rainwater sampler sensor at Metro Manila (MM) site. WD monitoring at MM site was then resumed, but not at Los Baños (LB) for the rainwater sampler needed a total replacement.

On Dry Deposition (DD) monitoring, samples had been collected weekly using the Filter Pack method where gas and aerosols are trapped in a filter pack. Monitoring activities for DD had been conducted only at the remote site in 2015-2016 and DD at the urban site when it was resumed in 2019. The required parameters were measured based on the Technical Manual for Dry Deposition on Filter Pack Method, also published by the EANET.

1.4.2 PM2.5 Monitoring

A $PM_{2.5}$ monitoring instrument was provided by the Network Center to EMB in October 2017. The measurement is beta ray absorption method where $PM_{2.5}$ in the air is collected by the filter and β-ray is irradiated and the transmitted beam intensity is measured to obtain the mass concentration of fine particulate matter.

In addition, PM_{10} and $PM_{2.5}$ monitoring activities had been undertaken by DENR-EMB through its 16 Regional Offices.

1.4.3 Inland Aquatic Environment Monitoring

Monitoring activities for IAE had been conducted in accordance with the EANET Technical Manual for Inland Aquatic Environment Monitoring in East Asia (2010). On a quarterly basis, surface water with replicates were sampled directly at the center of the lake. For reference, measurements of

electric conductivity (EC), water temperature, pH and dissolved oxygen were done in situ using a portable water quality checker. Replicate samples were collected through grab sampling by using polyethylene bottles. The samples are preserved with ice in a chest while in transit to the corresponding Laboratory for analyses of the required parameters such EC, pH, alkalinity, cations and anions.

1.4.4 Catchment-scale Monitoring

Monitoring of some streams at the La Mesa Watershed had been done before so that during the said Technical Mission in January 2019, the Mission Team identified the catchment area at Tower 1 in the La Mesa Watershed in Lagro, Quezon City as the site for catchment-scale study of EANET in the Philippines. This is of important consideration because the La Mesa Watershed is the major source of water for the Metro Manila populace. Monitoring on a monthly basis had started on Catchment-scale through the collection of water sample from the stream at Tower 1 for the analysis of mandatory parameters in accordance with the Guideline for Catchment-scale Monitoring in East Asia. La Mesa Watershed has a total area of 26.59 square kilometers and the catchment area is 0.186 square kilometers, which is of loamy-sand soil. In the same Watershed the urban site for Soil and Vegetation monitoring had been earlier established. The Catchment-scale study site is around 9 km away from the MM site for wet and dry deposition monitoring. Data form these monitoring sites could be used for evaluation.

Chapter 2. Acid Deposition and Air Pollution in the Philippines and Their Environmental Impacts

2.1 State of acid deposition and air pollution

2.1.1 Wet deposition

Wet deposition is one form of acid deposition which is normally associated as acid rain. This happens when the sulfuric and nitric acid formed in the atmosphere mixed with rain, snow or fog and fall to the ground. Wet deposition has a substantial effect on ecosystem.

Based on the acceptable data during the five-year period (2015-2019), Figure 2.1 shows the Annual precipitation, Precipitation amount-weighted annual average pH and of EC for the three sites (Metro Manila or MM, Los Baños or LB and Mt. Sto. Tomas or MST), representing the urban, rural, and remote site, respectively. During 2015-2019, MST site had the highest precipitation averaging at 5,267 mm y^{-1}, followed by MM at 2,462 mm y^{-1} and lowest was in LB at 1657 mm y^{-1}. The annual average pH was 5.73 in MM, 6.29 in LB and 6.21 in MST, which were all above 5.6, the pH of normal rain. For the annual average EC, LB site shows the highest at 3.34 mS/m, then 2.25 mS/m in MM and the lowest at 0.50 mS/m in MST.

Figure 2.2 shows the precipitation amount-weighted annual average concentrations for NH_4^+ and Cl^- ions, which were highest in terms of mean concentrations relative to the other charged species monitored for WD samples. NH_4^+ level was highest in MM (urban site) with an average of 75.7

µmol/L. Los Baños Cl^- level in 2015 was quite high (92.0 µmol/L) compared with the levels in MM and MST during the period. The non-sea-salt SO_4^{2-} (nss-SO_4^{2-}) had an average of 15.8 µmol/L in MM, site, 12.4 in LB and 4.06 in MST. The concentration levels of NH_4^+, Cl^- and nss-SO_4^{2-} at MM site were all lowest in 2019.

It is shown in Figure 2.2 that non-sea-salt sulfate and nitrate levels were highest at urban site (MM), followed by the rural site (LB) and the remote site (MST) had the lowest levels. The levels of NH_4^+, Cl^-, SO_4^{2-} and NO_3^- at MM site were lowest in 2019.

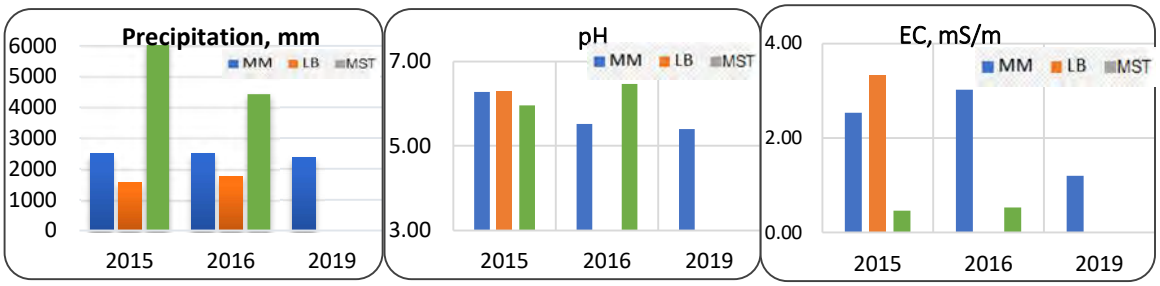


Figure 2.1. Annual mean of precipitation/pH/EC in MM, LB, and MST deposition monitoring sites in 2015-2019.

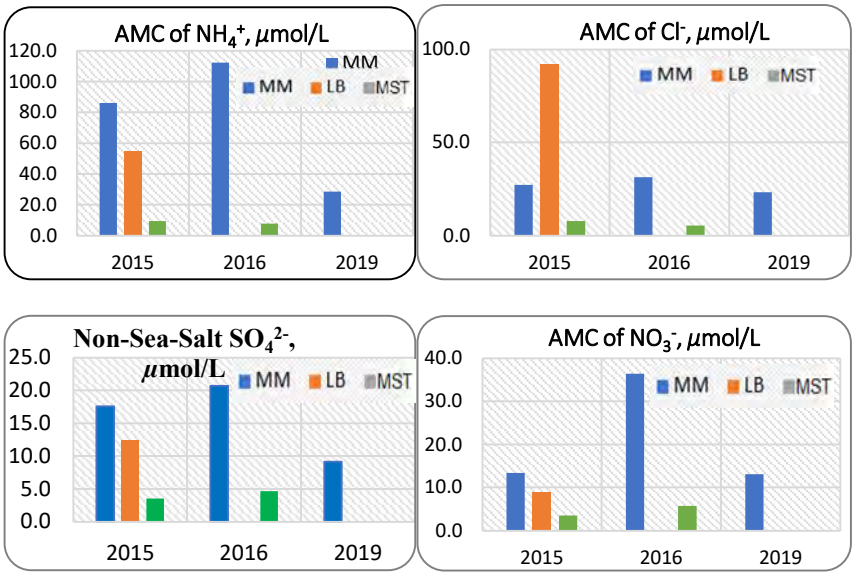


Figure 2.2. Annual mean concentration (AMC) of NH_4^+, Cl^-, non-sea-salt SO_4^{2-} and NO_3^- in MM, LB and MST monitoring sites in 2015-2019.

2.1.2 Dry deposition

Dry deposition is another form of acid deposition which airborne acids are removed from the air during fine and cloudy days. If inhaled dry deposition can caused health problems on humans. The annual data of dry deposition monitoring 2015 and 2016 are presented in Figure 2.3 with the annual average of gases (SO_2, HCl, NH_3), of anions in particulates (SO_4^{2-}, NO_3^-, Cl^-) and of cations (NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}) for dry DD monitoring at MST site in 2015-2016. Of the gases, NH_3 had the highest level, at 1.91 ppb. The average of SO_2 annual mean was 0.15 ppb while of HCl was 0.40 ppb.

For particulates, of highest anion concentration was 0.30 µg/m^3 SO_4^{2-} in 2016. The NO_3^- and Cl^- concentrations averaged at 0.20 µg/m^3 and 0.06 µg/m^3. Of the cations in particulates, concentrations were all below 0.60 µg/m^3, with Na^+ of the highest concentration, followed by Ca^{2+}, K^+, Mg^{2+}, and NH_4^+ the lowest concentration.

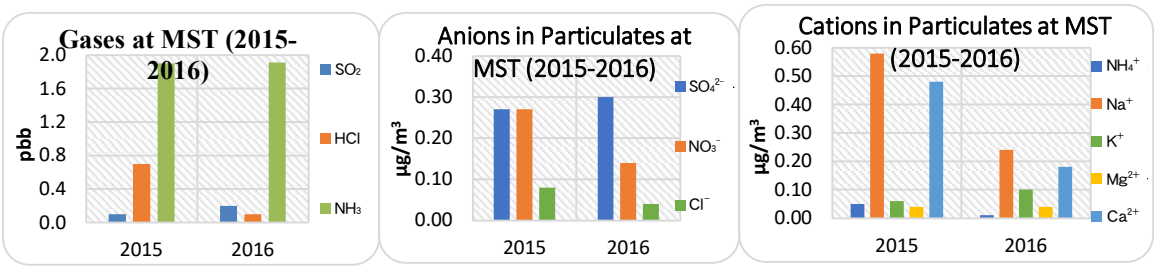


Figure 2.3. Annual Mean Concentration for Gases, Anions and Cations in Particulates Matter in MST in 2015-2016.

2.1.3 $PM_{2.5}$ Data

The $PM_{2.5}$ monitoring equipment from the Network Center was installed at the Manila Observatory grounds, the urban site for deposition monitoring. Figure 2.4 shows the daily average level of $PM_{2.5}$ during October 2017 to December 2019. The lacking data was due to the malfunctioning of the automatic voltage regulator of the equipment.

On the other hand, PM_{10} and $PM_{2.5}$ monitoring data had been generated in all the 16 Regions of the Philippines during the 2015-2019 period. The data is summarized in Chapter 3 (Review of National Air Quality Management).

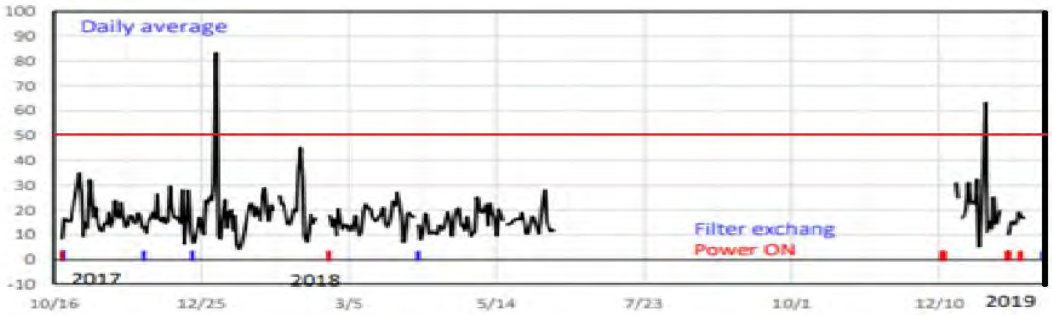


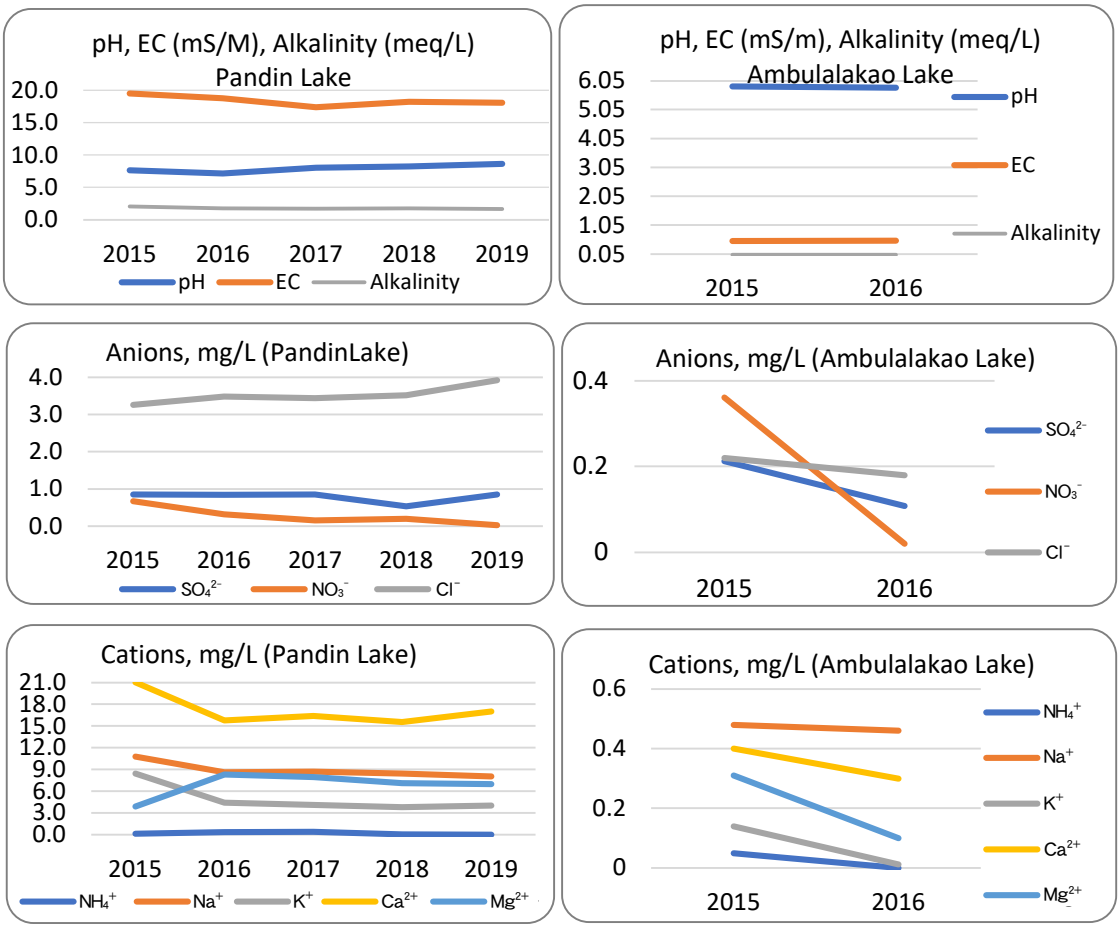
Figure 2.4. Daily average concentration from October 2017 to December 2019.

2.2 State of inland aquatic environment

Currently, the Philippines has two sites for Inland Aquatic Environment Monitoring, namely, Pandin Lake (rural site), located in San Pablo, Laguna, and Ambulalakao Lake (remote site) located in Kabayan, Benguet province. Pandin Lake is part of the Seven Lakes System in the area, which are of low-profile volcanic craters. As one of the best kept lakes, Pandin Lake is the most pristine of the Seven Lakes. It is considered oligotrophic because of the abundant plant and aquatic fauna surrounding the area. The Lake has no inlet while its outlet water drains into the Laguna de Bay through the Prinsa River while its recharge water comes from rainwater and underground. The Ambulalakao Lake in Kabayan Benguet is located in a sheltered valley with tall forest around it and

is said to be the cleanest body of water in the Cordillera Mountains.

The data from Pandin Lake covered the whole period while Ambulalakao Lake had data only in 2015 and 2016. Figure 2.5 shows the Annual Mean of each of the parameters measured at rural and remote sites. It is observable that pH levels in remote site were lower than those in Pandin Lake which ranged from 7.18 – 8.65 at slightly increasing trend. Average EC in remote site was quite low (0.51 mS/L) compared with the rural site (18.4 mS/m) which annual average levels were of decreasing trend. The average Alkalinity in remote site was 0.03 meq/L, also quite low compared with that in rural site at 1.8 meq/L.



Figures 2.5. Annual Mean of pH, EC, Alkalinity, anions, cations in Pandin Lake and in Ambulalakao Lake in 2015 – 2019.

The annual mean concentrations of anions and cations in Pandin Lake were also of higher levels than those of Ambulalakao Lake. On anions, Cl^- was the highest in Pandin Lake averaging at 3.52 mg/L, far above the highest 0.22 mg/L Cl^- level in Ambulalakao Lake. Pandin Lake had its average SO_4^{2-} level at 0.79 mg/L and NO_3^- at 0.27 mg/L of slightly decreasing trend during the period. On cations concentrations, the highest level at Pandin Lake was Ca^{2+} which averaged was 17.14 mg/L, followed by Na^+ at 8.90 mg/L, Mg^{2+} at 6.83 mg/L, K^+ at 4.95 mg/L, and NH_4^+ was of lowest level with the average at 0.17 mg/L. In 2015-2016, Ambulalakao Lake had its highest concentration also on Na^+ averaging at 0.47 mg/L, then Ca^{2+} (0.35 mg/L), Mg^{2+} (0.21 mg/L) while K^+ and NH_4^+ had levels less than 0.10 mg/L.

2.3 State of catchment monitoring

Stream water monitoring at Tower 1 in La Mesa Watershed started in 2017 with the recommendation of the 2016 ACAP Technical Mission Team that the stream at Tower 1 should be considered for catchment-scale monitoring. In January 2019, the ACAP Technical Mission Team confirmed that the said stream was suitable for Catchment-scale study. Consequently, collection of stream water from the site has been conducted on a monthly basis. Figure 2.6 shows graphs of the Annual Mean levels of the mandatory parameters during 2017 – 2019. The pH levels of the catchment stream at Tower 1 ranged from 7.63 – 7.76, the EC from 23.3 – 30.3 mS/m and Alkalinity (pH4.8) averaged at ranged from 2216 – 3679 $\mu mol_c/L$ and an average of 2889 $\mu mol_c/L$. For the anions annual mean concentrations, Cl^- had the highest levels averaging at 48.8 $\mu mol_c/L$, followed by SO_4^{2-},with an average of 43.4 $\mu mol_c/L$, PO_4^{3-} at 12.9 $\mu mol_c/L$, and the lowest was NO_3^- at 9.94 $\mu mol_c/L$. For the cations, Ca^{2+} had the highest with an average of 1396 $\mu mol_c/L$, then Mg^{2+} at 738.0 $\mu mol_c/L$, Na^+ at 679.0 $\mu mol_c/L$, K^+ at 35.1 $\mu mol_c/L$, and NH_4^+ was of lowest level with an average of 4.12 $\mu mol_c/L$.

Flow measurements were done in 2019 during April and December (summer months) with an average of 0.0231 m^3/s. A weir would be installed at the site of collection for flow measurement.

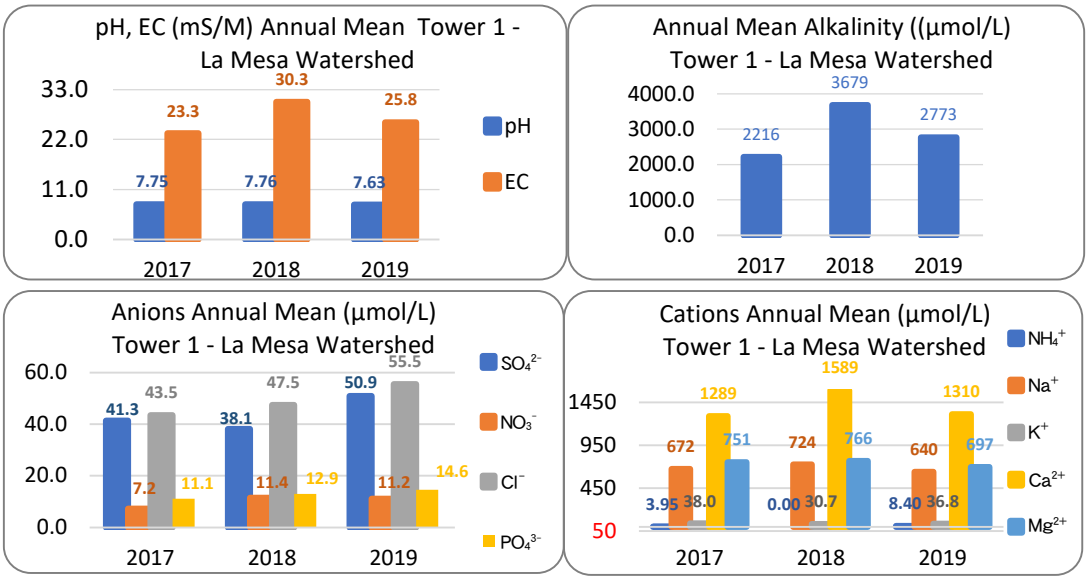


Figure 2.6. Annual Mean of pH, EC, alkalinity, SO_4^{2-}, NO_3^-, PO_4^{3-}, Cl^-, NH_4^+, Na^+, Ca^{2+}, Mg^{2+} at Tower 1 – La Mesa Watershed in 2017 – 2019.

2.4 Long-term monitoring on wet deposition and inland aquatic environment

The trends for 20 years are shown by adding the data from 2000 to 2014 to the above-mentioned data after 2015 in Section 2.1.1. Figure 2.7 shows variations in precipitation and wet deposition of H^+, nss-SO_4^{2-}, NO_3^-, NH_4^+, and nss-Ca^{2+} in equivalent basis over 20 years. Precipitation was highest at Mount Santo Tomas in the northern part of Luzon Island, followed by Metro Manila and Los Baños. No clear trend was observed in the secular variation of precipitation at the three sites. In Manila, nss-SO_4^{2-}, which is an index of sulfuric acid that acidifies the environment, was observed to be deposited in a larger amount than the other two sites.

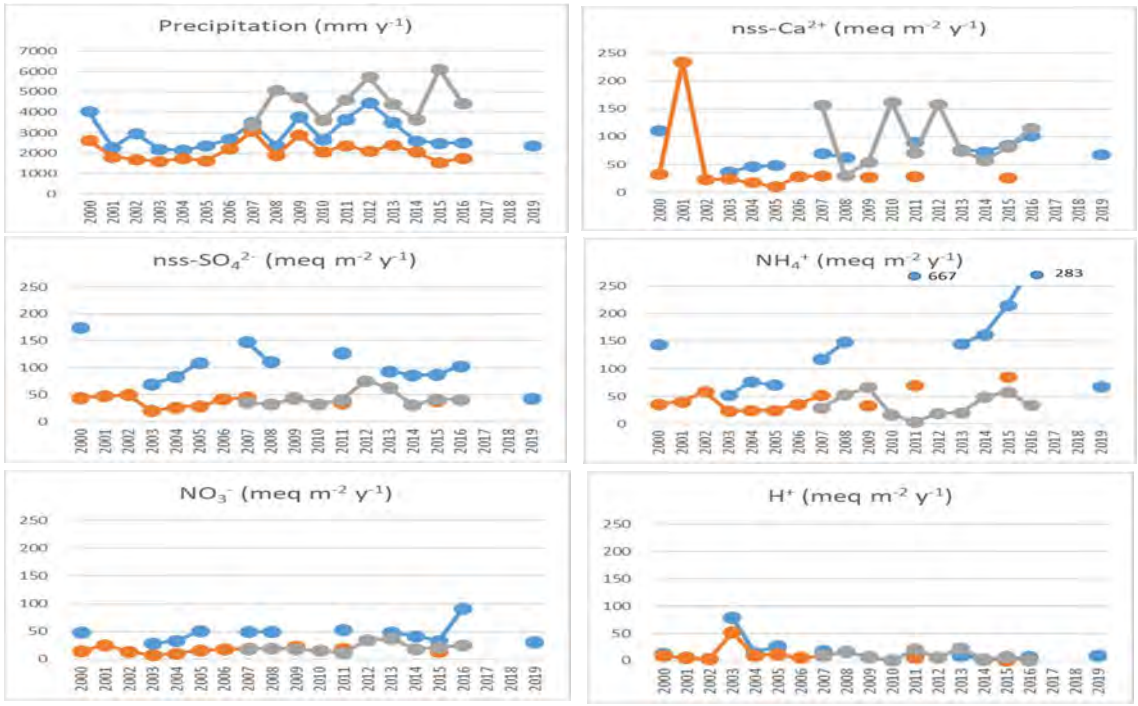


Figure 2.7. Long-term trends of precipitation and wet deposition in the Philippines (2000-2019).

During the monitoring period, decreasing trend of nss-SO_4^{2-} could be seen in Metro Manila and almost stable deposition amounts had been monitored in the other two sites. The relation among the three sites was also recognized in the wet deposition of nitrate, an indicator of nitric acid. Large deposition of 30 mmol m^{-2} y^{-1} or more were observed in MM. At the other two sites, Los Baños and Mt. Sto. Tomas, the deposition amount was in the range of 10-30 mmol m^{-2} y^{-1}. Temporal trends of nitrate deposition could not be seen clearly in the three sites. Comparing with the acidic components, base cations (NH_4^+ and nss-Ca^{2+}) had shown large deposition. Especially, large deposition of ammonium ion could be observed in Metro Manila site.

Figure 2.8 shows the relationship between total acidic and basic depositions observed in the three sites during the 20-year period. It was confirmed that total basic deposition amounts were almost same or higher than those of total acidic deposition amounts in all the three sites in this period. Therefore, significant influence on acidification had been considered to be limited in the monitoring area.

As shown in Figure 2.9, the long-term monitoring had been conducted also in inland aquatic environment, Pandin Lake and Ambulalakao Lake since 2005 and 2004, respectively. Excluding the 2009 data in Ambulalakao Lake, stable data of pH, EC, and alkalinity have been observed in both lakes. Especially in Ambulalakao Lake, it is confirmed that clean environment has been kept for long time.

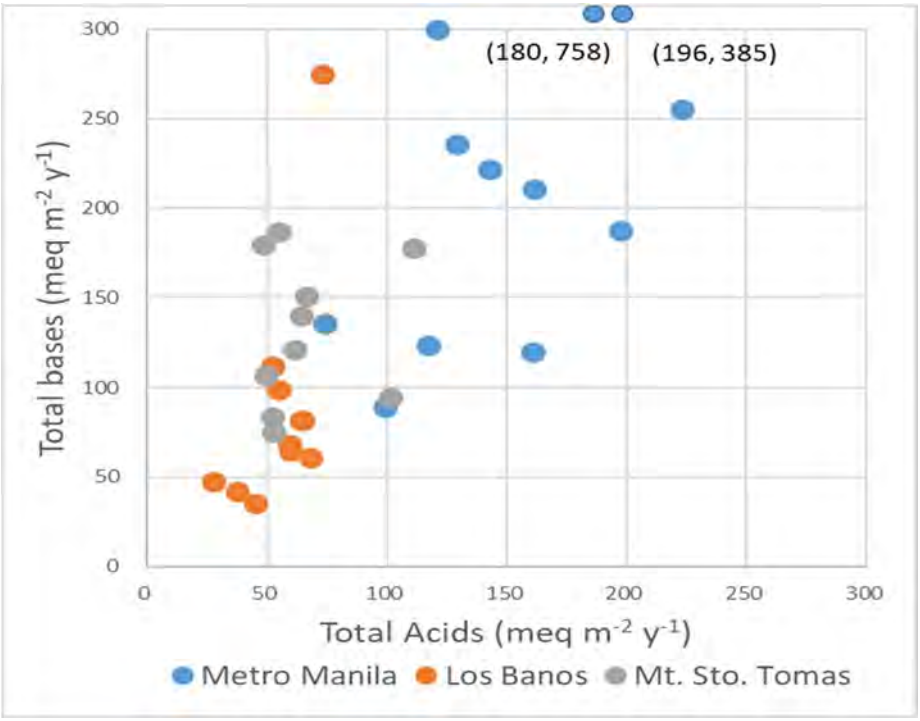


Figure 2.8. Relationship between total acids and bases depositions observed in three sites in 2000-2019. Total acids and total bases mean sum of acidic substances (nss-SO_4^{2-} and NO_3^-) and sum of basic substances (NH_4^+ and nss-Ca^{2+}), respectively.

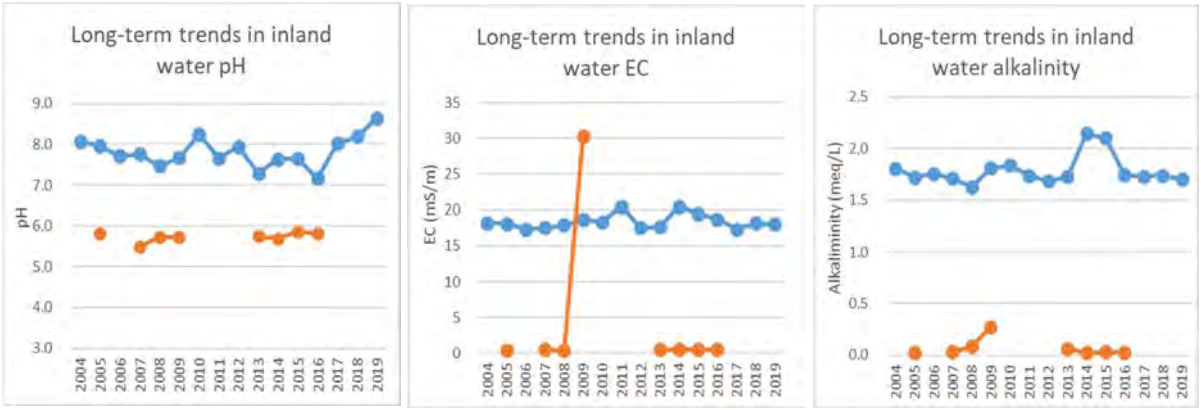


Figure 2.9. Long-term trends in inland water pH, EC, and Alkalinity.

2.5 Overall analysis

Comparing the average concentration levels of the WD parameters during the third and fourth periods, nss-SO_4^{2-}, Cl^- and Mg^{2+} were more or less of similar levels. Though NH_4^+ level in MM site was highest in 2015-2019, the level during 2010-2014 decreased from 95.1 μmol/L to 75.7 μmol/L in 2015-2019. LB site however increased from 29.4 μmol/L to 55.0 μmol/L. Levels of all other measured parameters at the three sites had no significant change during the two periods.

In the long-term data analysis for 20 years from 2000 to 2019, decreasing trend of nss-SO_4^{2-} could be seen in Metro Manila and almost stable deposition amounts had been monitored in the other two

sites, Los Baños and Mt. Sto. Tomas. Temporal trends of nitrate deposition couldn't be seen clearly in the three sites. Comparing with the acidic components, base cations (NH_4^+ and nss-Ca^{2+}) have shown large depositions. Especially, large deposition of ammonium ion could be observed in Metro Manila site.

The relationship between total acidic and basic wet depositions observed in the three sites during the 20 years (2000-2019) was analyzed. It was confirmed that total basic deposition amounts were almost same or higher than that of total acidic deposition amounts in three sites in this period. Therefore, significant influence on acidification have been considered to be limited in the monitoring area.

With the data generated on IAE monitoring during the period, no large variation was observed on any of the parameters measured. Comparing the third and fourth periods, the average level of NO_3^- in Pandin Lake decreased from 1.242 mg/L to 0.274 mg/L while levels of pH, EC and all the other anions and cations were more or less the same. In Ambulalakao Lake, average pH during the third period was 5.72 and 5.83 during the fourth period. All other parameters in Ambulalakao Lake (remote site) were of low levels during both periods. On CS monitoring, no large variation is observed on any of the parameters measured.

Long-term monitoring has been also performed even in inland aquatic environment, Pandin Lake and Ambulalakao Lake since 2004. Stable data of pH, EC, and alkalinity have been observed in the two lakes. Especially in Ambulalakao Lake, it is confirmed that clean environment has been kept for long time.

Chapter 3. Review of National Air Quality Management

3.1 Air Quality

The Philippine Clean Air Act of 1999 or Republic Act 8749 (RA 8749) aims to achieve and maintain healthy air for all. It contains the legal mandate of governmental agencies in managing the outdoor air quality in the Philippines, listing all potential sources of outdoor air pollution while providing ambient air quality guidelines and standards for emissions. Its implementation is a multisectoral undertaking, led by the Department of Environment and Natural Resources.

The DENR – EMB is the mandated lead agency in the implementation of RA 8749. DENR-EMB is mainly tasked to monitor the outdoor air pollution; prepare a National Air Quality Status Report which shall be used as a basis in formulating the Integrated Air Quality Improvement Framework; and issue rules and regulations in the implementation of the Act.

3.2 State of Air Quality

3.2.1 Emission Inventory

Emissions Inventory is conducted every three (3) years pursuant to the provisions under the Philippine Clean Air Act of 1999. Emissions inventory estimates emissions coming from stationary, mobile and area sources.

The contribution of emissions from mobile sources increased from 65% in 2015 to 74% in 2018 (Figure 3.1). Its levels also exhibited increasing trend from 2002 to 2018, at a rate of two million tons per year. Emissions Inventory by source conducted in 2015 showed that the majority (65%) of air pollutants came from mobile sources (cars, motorcycles, trucks, and buses). Almost 21% were contributed by stationary sources (power plants and factories). The rest (14%) were from area sources (construction activities, open burning of solid wastes and kaingin in the uplands, among others). However, the Emissions Inventory for the National Capital Region (NCR) in the same year reported a huge 88% contribution of mobile sources to air pollution in the area compared to only 10% from stationary sources and a mere 2% from area sources. The National Emissions Inventory of 2015 also shows the contribution of different types of pollutants such as volatile organic compounds (VOC), sulfur oxides (SO_X), nitrogen oxides (NO_X), carbon monoxide (CO) and particulate matter (PM) to emissions nationwide. The major pollutants coming from mobile sources are VOC (91%) and CO (89%). Stationary sources generate substantial amounts of gases such as SO_X (72%) and NO_X (39%) while area sources produce mostly PM (45%)[1].

In the latest National Emissions Inventory by source conducted in 2018, the majority (74%) of air pollutants came from mobile sources as stated above. Fifteen percent (15%) were contributed by stationary sources and the rest (11%) were from area sources[2]. The major pollutants coming from mobile sources are VOC (94.20%) and CO (88%). Stationary sources generate substantial amounts of gases such as SO_X (87.80%) and NO_X (22.90%) while area sources produce mostly particulate matter (36.96%)[2].

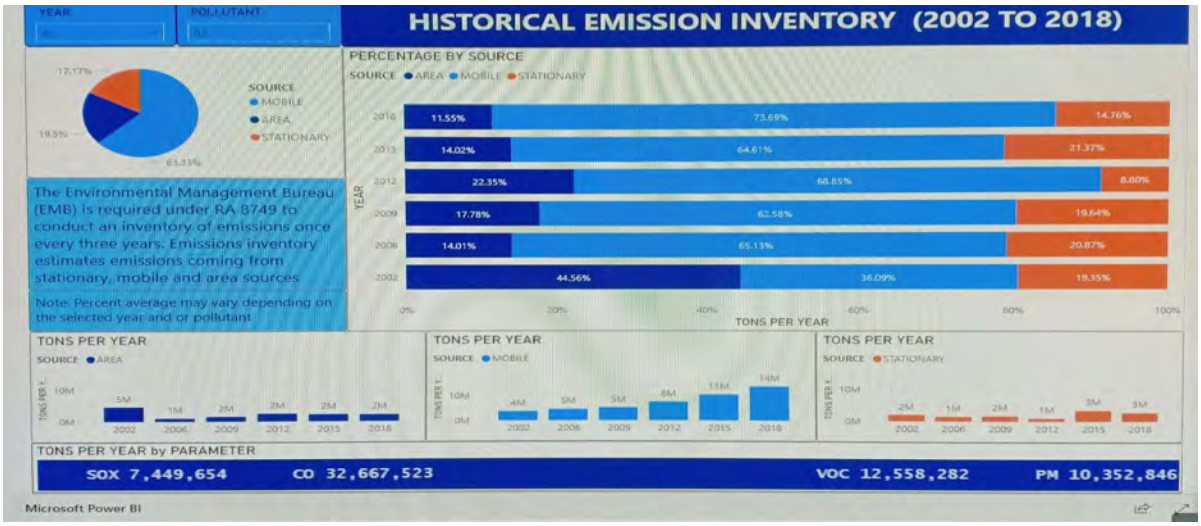


Figure 3.1. Six-year comparative Emissions Inventory (%) per source in tons per year.

3.2.2 Air Quality Monitoring Data

[1] National Air Quality Status Report (2008 - 2015). Department of Environment and Natural Resources. Environmental Management Bureau. Reference: https://air.emb.gov.ph/wp-content/uploads/2019/04/National-Air-Quality-Status-Report-2008-20151.pdf

[2] National Emissions Inventory 2018. Department of Environment and Natural Resources - Environmental Management Bureau. Reference: https://air.emb.gov.ph/emission-inventory-2018/

The Annual Guideline Value for Particulate Matter 10 (PM10) and PM2.5 are 60 ug/Ncm and 25 ug/Ncm, respectively. From the annual mean data generated in 2012 to 2018[3], the results in 2018 at PM10 stations located in DOH Cmpd. Rizal Avenue Sta Cruz, Manila (62 ug/Ncm), Plaza Garden Park, Central Business District, Lower Session Road, Baguio City (66 ug/Ncm), Plaza Burgos, Ilocos Sur, Vigan City (63 ug/Ncm), Oton National Elementary School, Oton, Iloilo (81 ug/Ncm), and Open Park in front of Toril District Hall, Agton St., Davao City (63 ug/Ncm) exceeded the annual guideline value. Data in 2019 however show that only Vigan City exceeded. On PM2.5 in 2019, the stations in Pateros Elementary School, Pateros City (27 ug/Ncm), City Plaza, San Carlos City, Pangasinan (67 ug/Ncm), Western Central Elementary School, Dagupan City, Pangasinan (63 ug/Ncm), and Calinan National High School, Quirino Avenue, Davao City (27 ug/Ncm) exceeded the annual guideline value. This might be attributed to human activities, emission from transport sector, industrial and commercial operations, among others.

As of 2019, there were 103 air quality monitoring stations nationwide. These manual and real-time stations are situated in highly urbanized cities and rural areas in different regions of the country. Monitoring stations keep track of criteria pollutants or air pollutants for which National Ambient Air Quality Guideline Values (NAAQGV) have been established. These pollutants include Total Suspended Particulates (TSP), Particulate Matter with diameter of less than 10 microns (PM_{10}), Particulate matter with diameter of less than 2.5 microns ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3). A historical $PM_{2.5}$ annual data is shown in Figure 3.2.

Furthermore, a set of pollution standard index of air quality, called the Air Quality Index (AQI) was formulated in line with the Clean Air Act (CAA). For the six criteria pollutants, the air quality can be described in terms of six levels depending on pollutant concentration: Good, Fair, Unhealthy for sensitive groups, Very unhealthy, Acutely unhealthy and Emergency. Daily reports of the AQI based on PM10 have been made available starting in 2014 at the four continuous monitoring stations in NCR (DLSU-Taft Ave. Manila, DPWH-Timog Quezon City, PLV-Valenzuela, and Commonwealth Ave. Quezon City), through DENR- Environmental Management Bureau (DENR-EMB) website: http:// www.emb.gov.ph. Air Quality Monitoring Data of the Philippines can be accessed thru the EMB Website (emb.gov.ph).

[3] National Air Quality Status Report 2016-2018: https://air.emb.gov.ph/wp-content/uploads/2021/07/NAQSR-2016-2018-FV.pdf

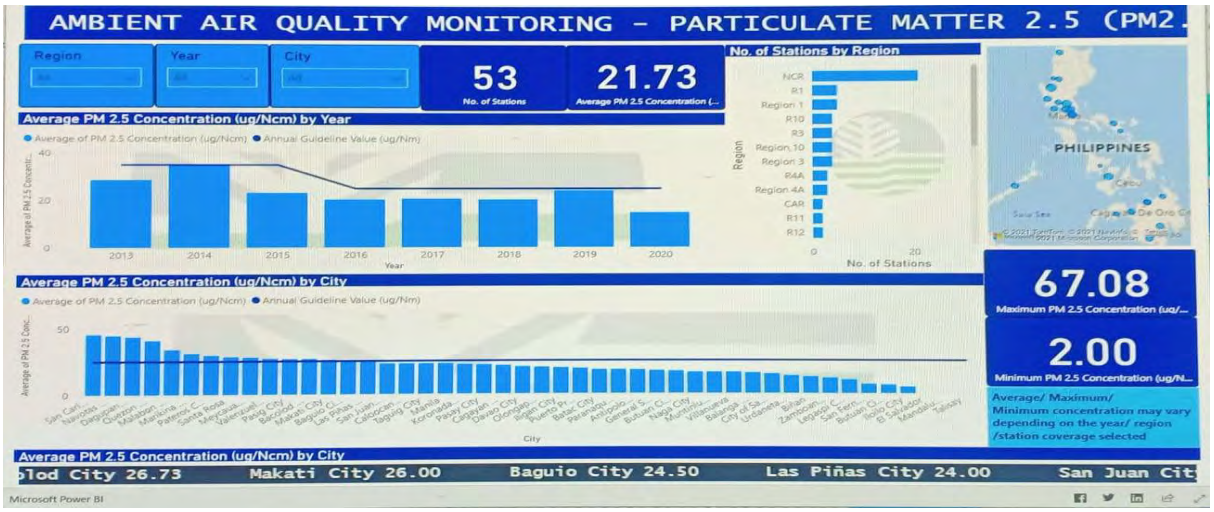


Figure 3.2. Historical $PM_{2.5}$ Annual Data.

3.3 Status of Management of Air Pollution Sources

Air Quality Management Programs of the DENR-EMB increases in performance from 2016 to 2019. Sources are categorized as Stationary, mobile and area as defined in RA 8749.

There are two (2) programs in the management of stationary sources.

a. The Linis Hangin (Clean Air) Program has two monitoring activities:

i. The issuance of Certificate of Conformity (Euro 4) to industries, and

ii. Bantay Tsimeneya (Stack Monitoring) that take charge in the issuance of permit to operate (PO) for air, whether these are new application or renewal.

b. ***The Industrial Compliance Monitoring Program*** surveys the firms within the CAMANAVA area, major urban centers, and the rest of the Philippines

In the Management of mobile sources, the DENR-EMB monitors the Private Emission Testing Centers (PETCs) nationwide and requires them to submit an annual report.

3.4 Management of Stationary Sources

Pursuant to DENR Administrative Order (DAO) 2004 - 26, all source of air pollution subject to the Philippine Clean Air Act of 1999 (RA 8749) must have a valid Permit to Operate (PTO) issued by the EMB Regional Director. This policy was further enhanced wherein the issuance of PTO was included in the Online Permitting and Monitoring System (OPMS) to provide uniformity in the content and upgrade the monitoring of PTO.

One of the major thrusts of the DENR-EMB is to determine the "universe" of regulated entities in terms of Air Quality Management through the issuance of PTO. Figure 3.3 shows the chart and spatial distribution of PTOs nationwide.

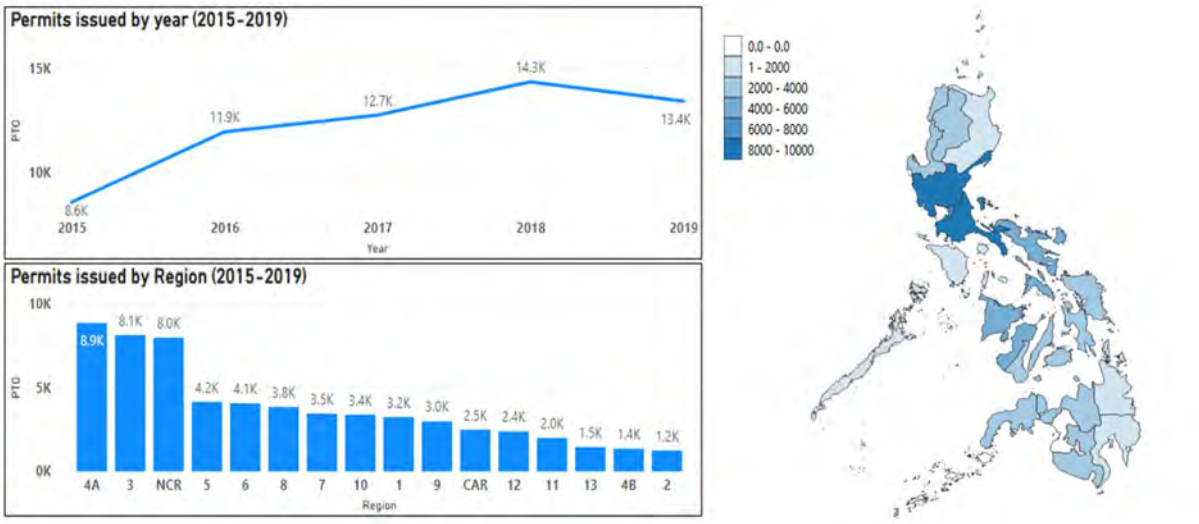


Figure 3.3. Nationwide Inventory of Permit to Operate (PTOs) – 2015 to 2019.

In compliance with Sections 8 and 38 of the Philippine Clean Air Act of 1999 and Rule XLVII Section 2 (c) of DAO 2000 – 81 (Implementing Rules and Regulations of the Clean Air Act), the DENR through the EMB has established the Sampling Assessment Team (SAT) through Special Order No. 2014 – 207, later amended thru S.O. No. 2018 – 296, to monitor the emissions from Air Pollution Source Installations (APSI) of industries nationwide. In view of the magnitude of APSIs installed nationwide (Figure 3.4), the Accreditation of Third-Party Source Emission Testing Firms (TPSETFs) thru DAO 2013 – 26 was also established to aid in the above-mentioned mandate of the DENR-EMB. One of the major responsibilities of the SAT is to monitor, review, and accredit TPSETFs, where remote assessment can be employed (Figure 3.5). The List of Accredited TPSETF can be seen at EMB Website.

As of 2019, a total of twenty–two (22) firms with thirty (30) teams have been accredited as per accreditation procedures as stipulated in DAO 2013 – 26.

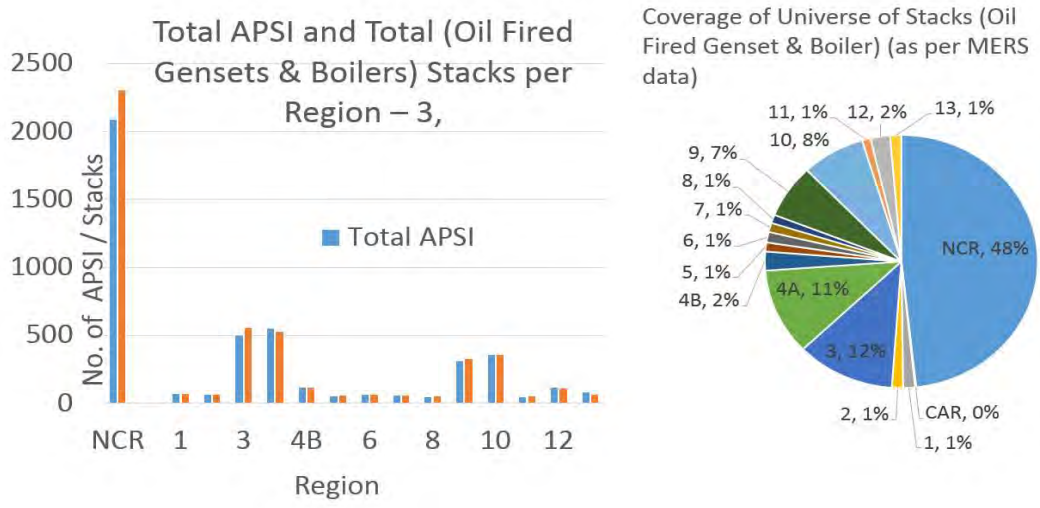


Figure 3.4. Total APSI vs Total Stacks for Generator Sets and Boilers.

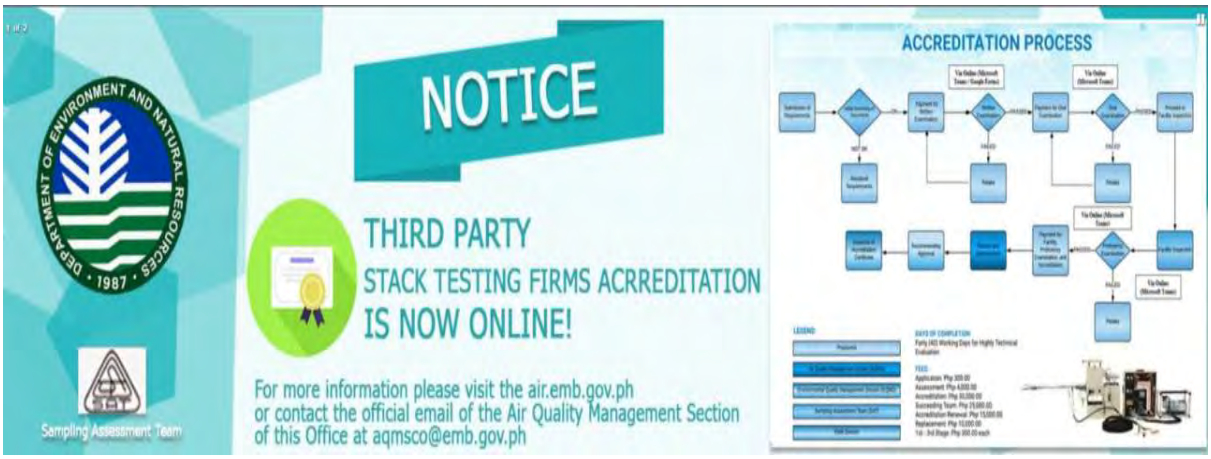


Figure 3.5. Remote Assessment of TPSETF Accreditation.

Pursuant to Section 38 of RA 8749, the Department shall require any person who owns or operates any emission source to:
(a) Establish and maintain relevant records;
(b) Make relevant Reports;
(c) Install, use, and maintain monitoring equipment or methods.

In relation to this, Continuous Emission Monitoring System/Continuous Opacity Monitoring System (CEMS/COMS) are those monitoring equipment used by major sources defined under Rule XXV of DAO 2000 – 81 and those requirements under DAO 2007 – 22, the Guidelines on the Requirements for CEMS and other Acceptable Protocols.

Another activity in relation to industrial emission management is the monitoring of CEMS whether it is calibrated through Relative Accuracy Test Audit (RATA) or Relative Accuracy Audit (RAA) or Cylinder Gas Audit (CGA). Calibration ensures that the data collected by the CEMS is accurate. Observation of such activities will pave the way in the formulation of a new policy which is the accreditation of third-party audit service providers to ensure that the service paid for by the industry is legitimate.

Pursuant to DAO 2017 - 14, the EMB has intensified its efforts in monitoring emissions from sources required to install CEMS/COMS through the online submission of emissions data to the EMB File Transfer Protocol (FTP) system. On September 27, 2019, a Memorandum was signed by Secretary Cimatu revoking the Memorandum of Secretary Atienza dated 2 March 2009; thus, requiring all sources to test for SO_X as SO_2 submit Source Emission Test (SET) sampling in addition to SO_2 ambient air sampling.

3.5 Management of Mobile Sources

Mobile sources remain the largest source of emissions, due to continuous operation of old and non-compliant to emission standards motor vehicles, traffic congestion, and the continuous increase of motor vehicles operating on the roads, among others.

The DENR-EMB monitors the operations of the Private Emission Testing Centers (PETCs), issues

Certificate of Conformity (COC) to new vehicles prior to registration in the Country. Since the number of motor vehicles registered in the country increases through the years (Figure 3.6), the actual number of COCs issuance also increases. The issued COC in 2016 (388) increased by more than 30% the following year (504).

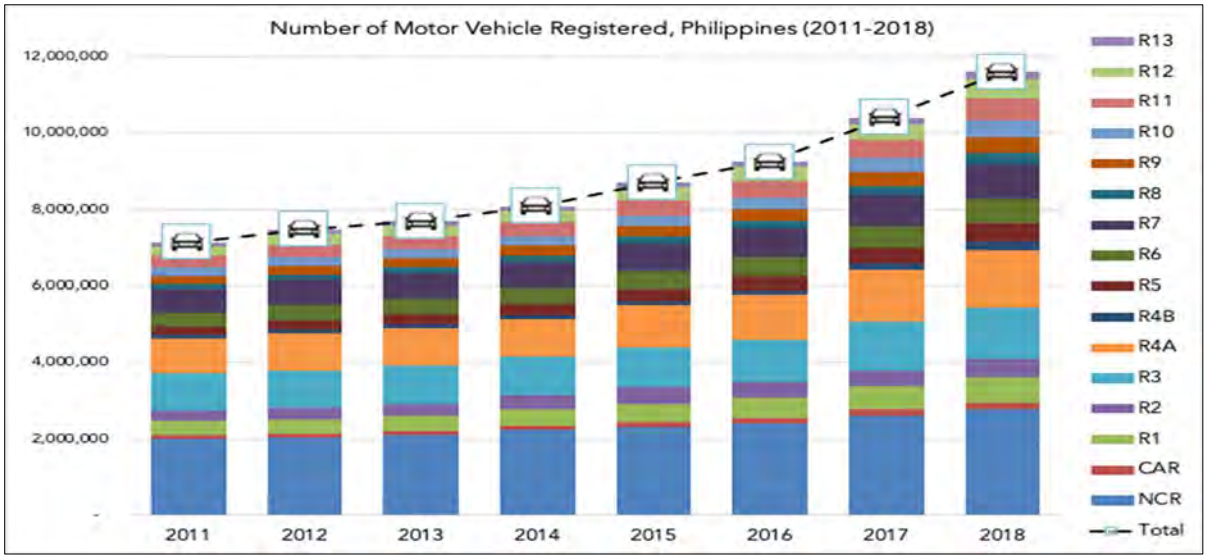


Figure 3.6. Number of motor vehicles registered through the years: new + renewal. (Source: LTO official website).

Several measures were carried out to reduce mobile emissions. For brand new motor vehicles, all vehicle types must meet the emission standard before they are introduced in the market for sale. They should be evaluated for their compliance with the prescribed exhaust emission limits/standards before a Certificate of Conformity (COC) is issued. Pursuant to RA 8749 and its IRR, COCs are issued to all brand new motor vehicle models/types that comply with the specified emission limits. This is to ensure that the vehicle complies with the emission standard set pursuant to CAA. The increase in the number of issued COC starting January 2015 is due to increased number of Euro 2/II COC applications which ended in December 2015, as per the policy issued by the Department on the implementation of Euro 4/IV Emission Compliance (DAO 2015-04) which began in 2016. Pursuant to RA 8749, Private Emission Testing Center (PETC) are Department of Trade and Industry (DTI) accredited and Department of Transportation (DOTr)- authorized, while the emission testing equipment are DENR-certified. Monitoring of PETCs is accomplished through a composite team comprised of DTI, DENR and DOTr-Land Transportation Office (LTO). The number of monitored PETCs and COCs issued are shown in Table 2.

Table 2 Number of PETCs monitored and COCs issued

		2016	2017	2018	2019
Linis Hangin Program (New vehicles)	COC Issued	388	504	615	610
Monitoring of Private Emissions Testing Centers (PETCs)	No. of PETC monitored and report submitted	578	673	637	678

Although EMB-DENR is not the lead implementing agency for vehicular emission control but

invoking its mandate as the lead implementing agency of the CAA, two major activities were undertaken, namely, the roadside anti-smoke belching (ASB) operation and the free garage emission testing specifically for PUVs such as buses and jeepneys. There were also seminars and lectures on preventive maintenance, fuel efficiency and eco-safe driving. In 2015, the DENR issued an administrative order directing the implementation of Motor Vehicle Emission limits for Euro 4/IV and In-use Vehicle Emission Standards beginning July 1, 2015, with full implementation on January 1, 2016. In support to this, another government agency in the Philippines, Department of Energy, issued a circular mandating the manufacture and sale of Euro IV automotive diesel oil and gasoline.

3.6 Management of Area Sources

Management of Area Sources such as smoking, open burning, and nuisances (noise and odor) are generally devolved to the Local Government Units (LGUs) through the implementation of local ordinances or resolutions.

The use of firecrackers during New Year's celebration should be regulated as it contributes extremely high levels of pollutants in the atmosphere. Municipalities can focus on controlled use of fireworks in public places. To better understand the pollution contribution of fireworks, chemical analyses of its composition and emissions can also be done. RA 7183 regulates the sale, manufacture, distribution and use of firecrackers and other pyrotechnic devices, and this law should be more stringently implemented considering the effects of such materials on air quality and the corresponding health risks involved.

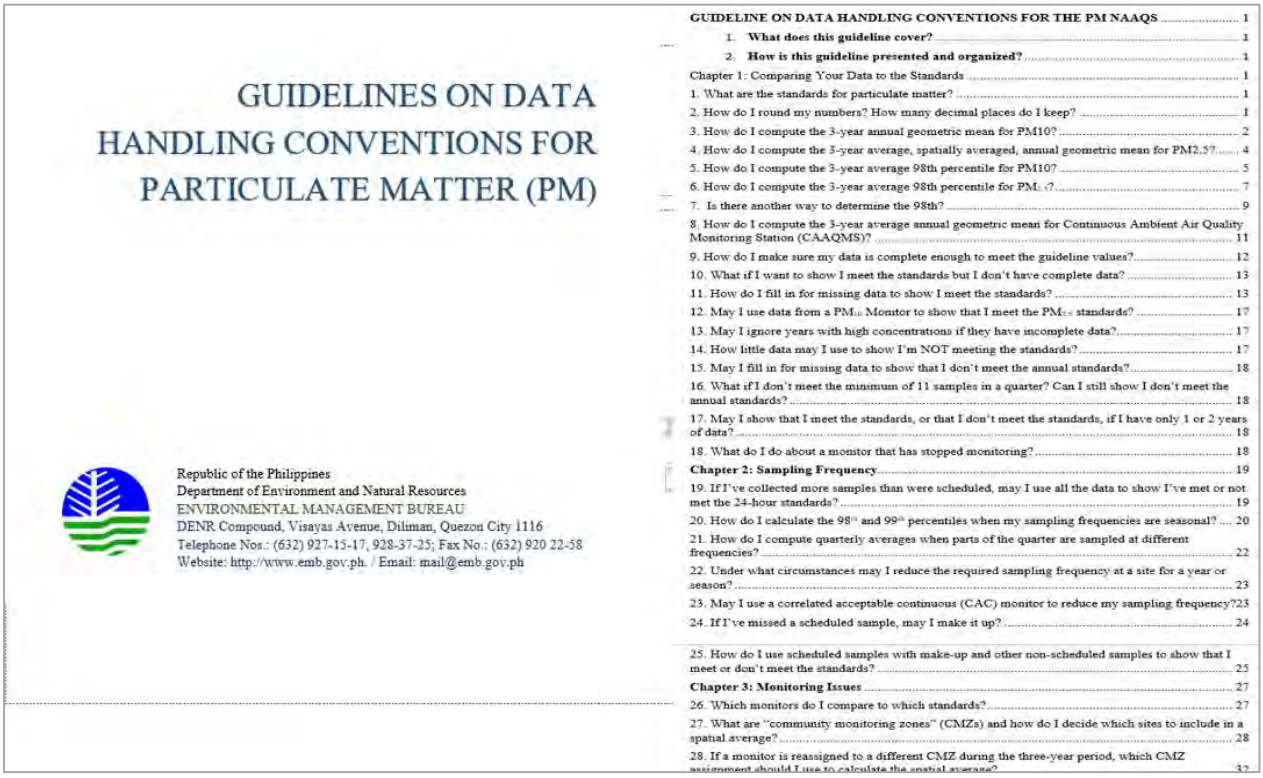
3.7 Policies Formulated and Approved in FY 2016-2019

Shown in Table 3 are the policies issued in CY 2016-2019 and Figure 3.7 is a photocopy of proposed "Guidelines on Data Handling Conventions for Particulate Matter. The policies have been drafted with either a Memorandum Circular or DENR Administrative Order and have undergone public consultations with relevant stakeholders such as government agencies, academe, Third Party Source Emission Testing Firms, EMB Regional Offices, and Industries.

One major factor considered in the implementation of most policies with regards to industrial sources is the economic implications to the company which may be imposed to the consumers but should never hinder the mandate of the DENR-EMB to provide a clean and healthy environment to protect public health and safety and general welfare.

Table 3 Policies issued from CY 2016-2019

Year	Policy
2019	1. Memorandum from the Secretary to all EMB Regional Directors dated September 27, 2019: Memorandum from the Secretary to all EMB Regional Directors dated September 27, 2019 2. EMB Memorandum Circular (MC) No. 2019-007: Guidelines for the conduct of Isokinetic Sampling in Tapered Stacks
2018	1. EMB MC No. 2018-005: Implementing Guidelines for the Conduct of an Actual Inspection of New Motor Vehicles in Relation to the Issuance of a Certificate of Conformity (COC)
2016	1. DENR Administrative Order (DAO) No. 2016-28: Providing for new fees and charges for various services of the Environmental Management Bureau 2. EMB MC No. 2016-008: Clarificatory Guidelines on the conduct of Stack Emission Tests by DENR-EMB and Its Accredited Third-Party Source Emission Testing Firms 3. DAO No. 2016-23: Adoption of EURO 4/IV Emissions Limits/Standards


GUIDELINES ON DATA HANDLING CONVENTIONS FOR PARTICULATE MATTER (PM)

Republic of the Philippines
Department of Environment and Natural Resources
ENVIRONMENTAL MANAGEMENT BUREAU
DENR Compound, Visayas Avenue, Diliman, Quezon City 1116
Telephone Nos.: (632) 927-15-17, 928-37-25; Fax No.: (632) 920 22-58
Website: http://www.emb.gov.ph. / Email: mail@emb.gov.ph

GUIDELINE ON DATA HANDLING CONVENTIONS FOR THE PM NAAQS 1
1. What does this guideline cover? 1
2. How is this guideline presented and organized? 1
Chapter 1: Comparing Your Data to the Standards 1
1. What are the standards for particulate matter? 1
2. How do I round my numbers? How many decimal places do I keep? 1
3. How do I compute the 3-year annual geometric mean for PM10? 2
4. How do I compute the 3-year average, spatially averaged, annual geometric mean for PM2.5? 4
5. How do I compute the 3-year average 98th percentile for PM10? 5
6. How do I compute the 3-year average 98th percentile for PM2.5? 7
7. Is there another way to determine the 98th? 9
8. How do I compute the 3-year average annual geometric mean for Continuous Ambient Air Quality Monitoring Station (CAAQMS)? 11
9. How do I make sure my data is complete enough to meet the guideline values? 12
10. What if I want to show I meet the standards but I don't have complete data? 13
11. How do I fill in for missing data to show I meet the standards? 13
12. May I use data from a PM_{10} Monitor to show that I meet the $PM_{2.5}$ standards? 17
13. May I ignore years with high concentrations if they have incomplete data? 17
14. How little data may I use to show I'm NOT meeting the standards? 17
15. May I fill in for missing data to show that I don't meet the annual standards? 18
16. What if I don't meet the minimum of 11 samples in a quarter? Can I still show I don't meet the annual standards? 18
17. May I show that I meet the standards, or that I don't meet the standards, if I have only 1 or 2 years of data? 18
18. What do I do about a monitor that has stopped monitoring? 18
Chapter 2: Sampling Frequency 19
19. If I've collected more samples than were scheduled, may I use all the data to show I've met or not met the 24-hour standards? 19
20. How do I calculate the 98th and 99th percentiles when my sampling frequencies are seasonal? 20
21. How do I compute quarterly averages when parts of the quarter are sampled at different frequencies? 22
22. Under what circumstances may I reduce the required sampling frequency at a site for a year or season? 23
23. May I use a correlated acceptable continuous (CAC) monitor to reduce my sampling frequency? 23
24. If I've missed a scheduled sample, may I make it up? 24
25. How do I use scheduled samples with make-up and other non-scheduled samples to show that I meet or don't meet the standards? 25
Chapter 3: Monitoring Issues 27
26. Which monitors do I compare to which standards? 27
27. What are "community monitoring zones" (CMZs) and how do I decide which sites to include in a spatial average? 28
28. If a monitor is reassigned to a different CMZ during the three-year period, which CMZ assignment should I use to calculate the spatial average? 32

Figure 3.7. Proposed Manual for Data Handling of Particulate Matter (PM).

3.8 Public Awareness

EMB through its Environmental Education and Information Division conducted activities and developed Information, Education and Communication (IEC) and promotional materials for public awareness on air quality management. IEC materials such as infographics, brochures, flyers, audio-video presentations were developed, produced, and disseminated to other government offices, industry partners, civil societies, local government units, communities, schools, and academe. EMB also provided learning bundles on air quality management which can be found on the EMB website and Facebook page. The IEC and promotional materials include the following:

Infographics, Brochures, Flyers and Exhibit Materials

1. Ambient Air Pollution and Its Health Impact
2. Household Air Pollution and Its Health Impact
3. Clean Air Act- Implications to Local Government Units, Women and Small Business Establishments
4. Right to Breathe Clean Air: Step up Act Now flyer and exhibit material
5. Fact Sheets on Clean Air Act

Audio-Video Presentations

1. *Halina Sama Tayo* song and music video production to call for public awareness and actions for clean air
2. Virtual tour of the Air Quality Management Section office and demonstration of its air quality monitoring equipment.
3. *Hangin ay Ingatan Tungo sa Malinis na Kalikasan* AVP on air quality status, air pollution and its negative impacts on our health and environment
4. *Malinis na Sasakyan para sa Malinis na Hangin*: A video on promoting proper vehicle maintenance
5. Virtual tour of the Environmental Research and Laboratory Services Division of the EMB Central Office. The video featured the capabalities of the EMB Central Laboratory related to the implementation of the Philippine Clean Air Act

EMB also regularly conducted special event activities in celebration of National Clean Air Month in November every year. These activities have been in partnership with various stakeholders such as youth and community leaders, academe, technical experts, national government agencies and local government units. Major activities conducted were as follows:

- Conduct of National Clean Air Forum
- "Kilos para sa Kalikasan" clean air concert and exhibits
- Painting and Art Contests on Clean Air
- Video Blog Contest on Greening my Lifestyle for Blue Skies
- Bayanihan sa Daan Award- Philippine Bikable and Walkable Communities Award

Chapter 4. Conclusion and Summary

The Philippines Center for EANET, the DENR-EMB has continued to implement the various activities of the EANET which include (1) annual implementation of National Monitoring Plan for wet and dry deposition, soil and vegetation, inland aquatic environment and catchment-scale, (2) participation in the inter-laboratory comparison exercises, technical support and capacity building activities, promotion of research and studies related to acid deposition issues, promotion of public awareness, and cooperation and information exchange in national and regional levels. The DENR-EMB annually submits the monitoring data to the Network Center, the Asia Center for Air Pollution Research (ACAP) where the compilation, evaluation, storage and provision of data, promotion of quality assurance and quality control (QA/QC) activities are implemented.

Acid Deposition monitoring activities in the Philippines have been summarized by using data for the

last five years as well as data since the year 2000.
Comparing the average concentration levels of the WD parameters during the third and fourth periods, nss-SO_4^{2-}, Cl^- and Mg^{2+} were of similar levels. Though NH_4^+ level in MM site was of highest level in 2015-2019, the levels were lower than during 2010-2014, however, those of LB site increased. Levels of all other measured parameters at the three sites had no significant increase or decrease during the past two periods. In the long-term data analysis for 20 years from 2000 to 2019, decreasing trend of nss-SO_4^{2-} could be seen in Metro Manila and almost stable deposition amounts had been monitored in the other two sites, Los Baños and Mt. Sto. Tomas. Temporal trends of nitrate deposition could not be seen clearly in the three sites. Base cations (NH_4^+ and nss-Ca^{2+}) have showed large deposition with large deposition of ammonium in Metro Manila. In the relationship between total acidic and basic wet depositions observed in three sites, it was confirmed that total basic deposition amounts were almost same or higher than those of total acidic deposition amounts. Therefore, significant influence on acidification have been considered to be limited in the monitoring area.

There was no large variation on the data on IAE monitoring during the period on any of the parameters measured. Comparing the third and fourth periods, the average level of NO_3^- in Pandin Lake decreased, while levels of pH, EC and all the other anions and cations were more or less the same. The levels of all the parameters measured in Ambulalakao Lake were of low levels during both periods. Long-term monitoring has been also performed even in inland aquatic environment, Pandin Lake and Ambulalakao Lake since 2004. Stable data of pH, EC, and alkalinity have been observed in the two lakes. Especially in Ambulalakao Lake, it is confirmed that clean environment has been kept for long time.

National Air Quality Management that complied with the Philippine Clean Air Act of 1999 or Republic Act 8749 (RA 8749) is included in this report, which incorporates estimation of emission inventories, evaluation of air quality monitoring data, management of air pollution sources, management of stationary sources, management of mobile sources, and management area sources. The DENR–EMB is the mandated lead agency in the implementation of RA 8749. DENR–EMB is mainly tasked to monitor the outdoor air pollution, to prepare a National Air Quality Status Report which shall be used as a basis in formulating the Integrated Air Quality Improvement Framework and to issue rules and regulations in the implementation of the Act.

The monitoring capacity of the EMB remains to be at 103 stations nationwide, and a major challenge is the nearing obsolescence of some of the equipment. Although emissions from mobile sources increased from 65% in 2015 to 74% in 2018, the contributions from stationary sources decreased by 20% in the past three years, reflective of the larger coverage and management of stationary sources (including MSEs and standard generation sets).

Considering the qualified data sets across the country, in 2016, 2017 and 2018, the geometric mean of PM_{10} (39 μg/NCM, 41 μg/NCM, 39 μg/NCM, respectively) and $PM_{2.5}$ (20 μg/NCM, 21 μg/NCM, 20 μg/NCM, respectively) remain within the limits set by the National Ambient Air Quality Guideline Values for long-term monitoring, reflecting the effectiveness of recent policies in place (e.g., implementation of Euro 4 standards).
Meanwhile, the Total Suspended Particulates (TSP) has been declining thru the years, remain below

the guidelines in 2016 (89 μg/NCM), although went beyond the guidelines in 2017 (119 μg/NCM) and 2018 (97 μg/NCM), most probably due to a combination of natural and anthropogenic factors related to development (e.g., build-build-build program).

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National Air Quality Status Report 2016-2018: https://air.emb.gov.ph/wp-content/uploads/2021/07/ NAQSR-2016-2018-FV.pdf.

National Assessment on Acid Deposition in Korea

National Institute of Environmental Research

1.1 Basic Information on National Monitoring Activities

1.1.1 Outline of the activities on acid deposition and National Monitoring Plan

Korean government has taken comprehensive measures to reduce air pollutant emissions for the last six decades or so as it recognized the seriousness of air pollution caused by industrialization since the 1960's. That is why the country initiated a national air monitoring program in the middle of the 1970's. Then, photochemical assessment stations and hazardous air monitoring stations were added to the network in early 2000. In addition, atmospheric monitoring stations according to atmospheric characteristics have been added sequentially. As of 2020, there are 473 urban sites, 10 rural sites, 42 remote sites, 49 traffic sites under the national monitoring network and 42 monitoring sites for acid deposition shows that Korea is deeply aware of its importance.

Adverse effects of long range transport of air pollutants have a long history in Korea. Since its first record over six hundred years ago, the occurrence of Asian dusts and its harmful effects have been constantly reported. More importantly, North East Asia, one of the most populated regions in the world, has been experiencing extensive industrialization for the last half century and, consequently, a long range transport of air pollutants became a great public concern along with natural air pollutants and Asian dusts. As a result, rural sites and remote sites were established to evaluate the effect of long range transport on the air quality with the implementation of the acid deposition monitoring network.

Recognizing that international collaboration is required to effectively cope with trans-boundary air pollutants, Korea has actively promoted to and, if allowed, participated in regional endeavors such as LTP (Long range Transport Project), NEASPEC (North East Asian Sub-regional Program of Environmental Cooperation), EANET (Acid Monitoring Network in East Asia), NOWAP (Northwest Pacific Action Plan), ACE-ASIA (Asian Pacific Regional Aerosol Characterization Experiment), and KORUS-AQ(Korea-United States Air Quality study). Each of these has its own objectives and methods in addressing long range transport of air pollutants and other regional air quality problems.

EANET has become a leading acid deposition monitoring network in East Asia region since it was launched in 2001. As a founding member of EANET, Korea has been actively involved in various efforts of EANET; preparation of technical manuals; participation of QA/QC program; and regular monitoring of wet deposition, dry deposition, soil and vegetation. Monitoring data has been submitted to Network Center of EANET helping and used as the scientific information for the evaluation of both acid depositions and its impacts on ecosystems in East Asia. This year's national report covers characteristics of monitoring stations for EANET as well as preliminary analysis of monitoring data from 2000 to 2019.

1.1.2 Monitoring Stations

Korea selected Ganghwa, Imsil, and Jeju as the acid deposition monitoring sites for EANET. Ganghwa and Jeju were classified into "rural site", and Imsil, "remote site" according to the Technical Manual of EANET as summarized in Table 1.1.1. The locations and pictures of the stations are shown in Figure 1.1.1 and Figure 1.1.2, respectively. Ganghwa and Jeju sites are located near the coast to minimize anthropogenic emissions. Meanwhile, Imsil site is located near the mountain, which is subjected to soil and vegetation monitoring.

With the exception for those measured by automatic instruments, as noted in Table 1.1.2, NO_X, SO_2, O_3 and PM_{10} mass were monitored using air monitoring devices, and $PM_{2.5}$ compositions and the gaseous species, with filter pack. Together with chemical species, meteorological parameters such as wind speed, wind direction, air temperature, relative humidity, and solar radiation were observed at automatic weather stations in each site or nearby meteorological observatories.

Table 1.1.1 The characteristics and location of monitoring sites in Korea

Name of sites	Site classification	Latitude	Longitude	Heght above the sea level
Ganghwa	Rural	37° 42' N	126° 17' N	102 m
Imsil	Remote	33° 18' N	126° 10' N	50 m
Jeju	Rural	35° 36' N	126° 11' N	67 m

Table 1.1.2 The selected monitoring parameters and methods in Korea

Name of sites	Wet dep.	Dry dep.			
		Automatic			Filter pack
		SO_2, NO_2	O_3	PM	
Ganghwa	O	O	O	O	O
Imsil	O	O	O	O	O
Jeju	O	O	O	O	O

Figure 1.1.1. The geographical Location of EANET sites in Korea.

Figure 1.1.2. Pictures of monitoring sites in Korea ((a) Ganghwa, (b) Imsil, (c) Jeju).

1.1.3 Sampling and Measurements

1.1.3.1 Wet Deposition Monitoring

Acid deposition monitoring in Korea has been carried out according to the common methodologies specified in the "Technical Documents for Wet deposition Monitoring in East Asia" (hereafter denoted as Manual) in order to obtain the equivalent quality of monitoring data. Figure 1.1.3 shows wet-only samplers used for monitoring work. Precipitation samples were collected on a daily basis at 3 sites as listed in Table 1.1.3. Collected samples without biocides were shipped to laboratories and stored in a cooling box to preserve the sample composition. Rainwater major constituent were analyzed in line with the Manual as shown in Table 1.1.4. Ion Chromatography is a major analytical method for chemical analysis of anions and cations. All the data were checked using ion balance and conductivity agreement by calculating ion balance (R1) and conductivity agreement (R2). If a sample or individual datum has problems including "insufficient sample volume" or "low precision", the flags corresponding to the problems were attached to the data, following "Quality Assurance/Quality Control (QA/QC) Problem for Wet Deposition Monitoring in East Asia" (2000).

Figure 1.1.3. Wet deposition monitoring samplers.

Table 1.1.3 Sampling method for wet deposition monitoring in Korea

Name of sites	Site	Sampling frequency	Starting month
Ganghwa	Rural	Daily	March '99
Imsil	Remote	Daily	April '99
Jeju	Rural	Daily	January '99

Table 1.1.4 Sampling method for wet deposition monitoring in Korea

Name of sites	Site classification	Anion analysis	Cation analysis
Ganghwa	Rural	IC	IC
Imsil	Remote	IC	IC
Jeju	Rural	IC	IC

(Note) IC: *Ion Chromatography*

1.1.3.2 Dry Deposition Monitoring

SO_2, NO_2, O_3 - based-on the priority of the chemical species - and PM_{10} mass were monitored by automatic instruments as directed by "QA/QC Program for the Air Concentration Monitoring in East Asia (2001)" as noted in Table 1.1.5. Three-stage $PM_{2.5}$ filter pack sampler, shown in Figure 1.1.4, was used to monitor gaseous acids and bases, HNO_3, HCl, NH_3, and particulate components (SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, NH_4^+, Ca^{2+} and Mg^{2+}).

Table 1.1.5 Sampling method and parameter for dry deposition monitoring

Name of sites	Characteristics of site	Method	Parameter
Ganghwa	Rural	AT	SO_2, NO_2, O_3, PM_{10}
		FP	PMC in $PM_{2.5}$
Imsil	Remote	AT	SO_2, NO_2, O_3, PM_{10}
		FP	PMC in $PM_{2.5}$
Jeju	Rural	AT	SO_2, NO_2, O_3, PM_{10}
		FP	PMC in $PM_{2.5}$

(Note) AT: Automatic monitor, FP: Filter pack, PMC: Particulate matter components

URG (3 state $PM_{2.5}$ Sequential Sampler, USA)

Figure 1.1.4. Instruments used for dry deposition monitoring.

1.2 State of Acid Deposition in the Korea

1.2.1 State of wet deposition

The reliability of data was assessed based on the consistency between the measured electrical conductivity of precipitation and calculated one. If the balance of between cation and anion is not good, it means that there are errors in sampling or conducting chemical analysis or that there is one or more missed compositions in the precipitation. As presented in Figure 1.2.1., both regression and correlation analysis showed that the slope of the regression line is 0.9869, the coefficient of determination is 0.9868, and the balance between cation and anion was relatively good.

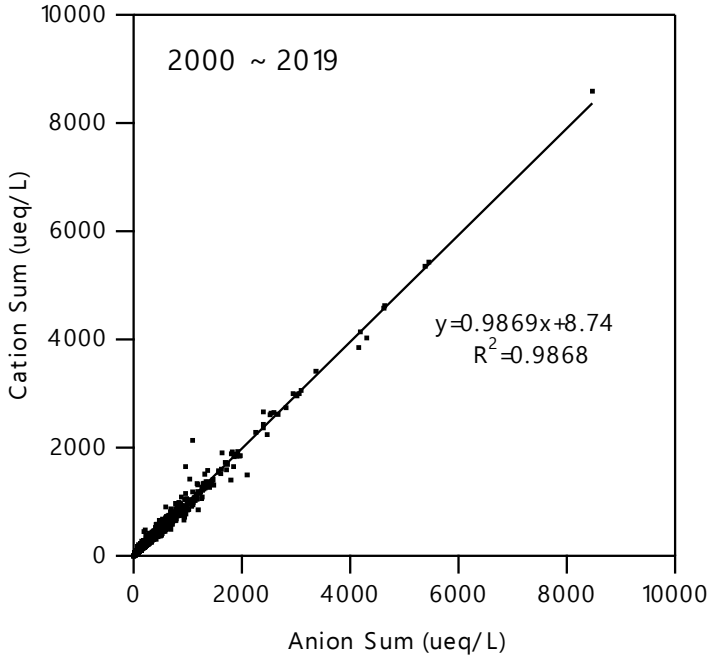

Figure 1.2.1. Relationship between total cation and anion in precipitation.

The EC of weak solution can be calculated using the equivalent conductance, and the result should be consistent with the EC value of samples, which can be calculated using the following equation.

ECcalc ($\mu S.cm^{-1}$) =

$\{349.7\times10^{(6-pH)} + 80.0\times2[SO_4^{2-}] + 71.5[NO_3^-] + 76.3[Cl^-] + 73.5[NH_4^+] + 50.1[Na^+] + 73.5[K^+]$

$+ 59.8\times2[Ca^{2+}] + 53.3\times2[Mg^{2+}] \} / 1000$

According to regression and correlation analyses of calculated conductivity and measured conductivity, as presented in Figure 1.2.2., the slope of the regression line is 1.0437 and the coefficient of determination is 0.9763.

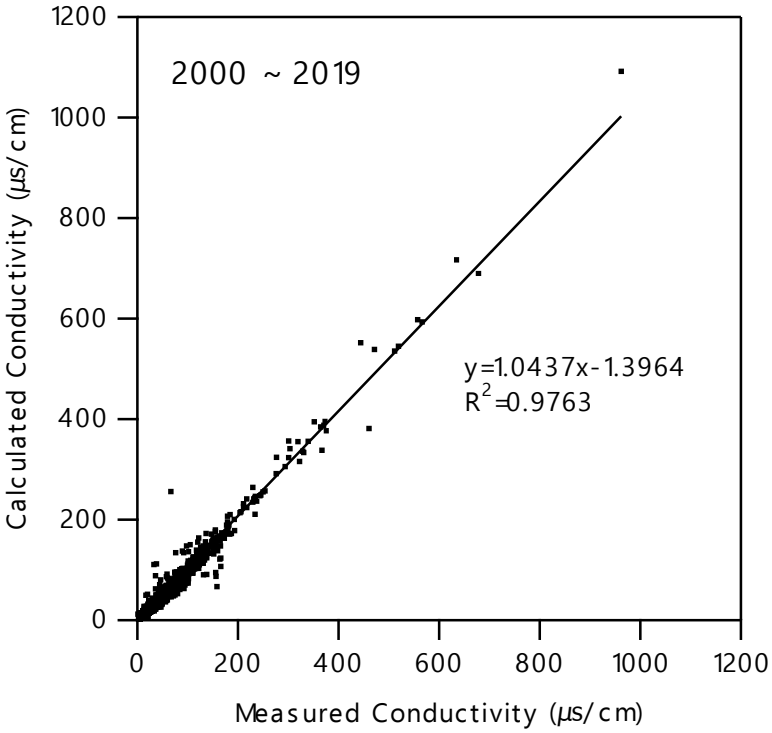

Figure 1.2.2. Relationship between the EC_{meas} and EC_{cal}.

Figure 1.2.3 presents the sum of major anion and cation ratio and SO_4^{2-} and NO_3^- ratio (2000-2019). NH_4^+ and Ca^{2+} were selected as major cations, and SO_4^{2-} and NO_3^- were selected as major anions. The sum of SO_4^{2-} and NO_3^- concentrations appeared to be slightly larger than the sum of NH_4^+ and Ca^{2+}. The ratios of major anions and cations were constantly checked as a key parameter for the ion balance and for rain water characteristics of sulfur and nitrogen containing species and checked together with major anion and cation ratios.

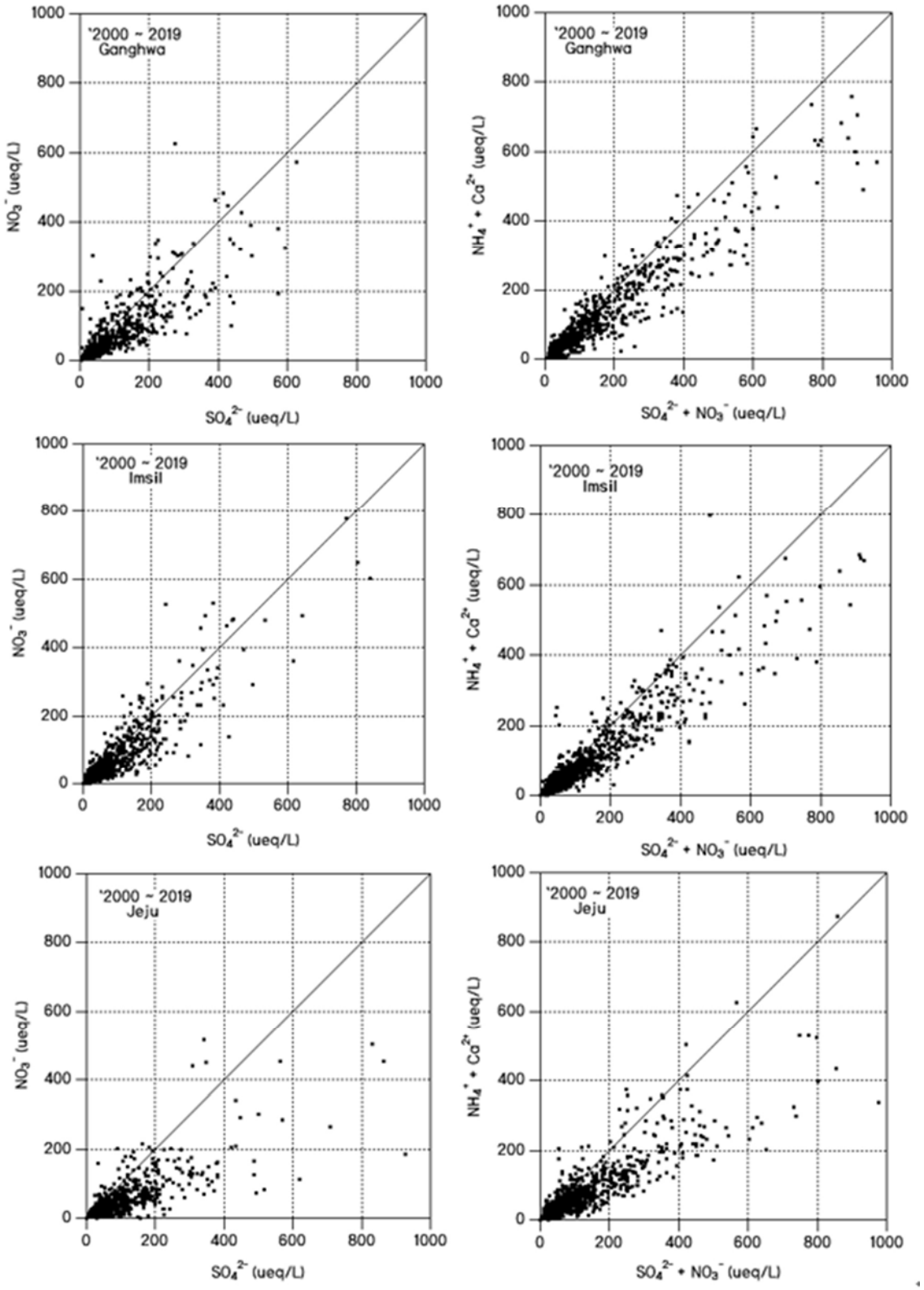

Figure 1.2.3. Ion balance check in Ganghwa, Imsil and Jeju (Unit: μeq/L).

pH is regarded as a major parameter characterizing acid rain mainly because it determines the acidity of rain waters. The annual mean pH was 5.2 in 2000, 5.0 in 2001, 5.0 in 2002, 4.8 in 2003, 4.7 in 2004, 4.8 in 2005, 4.8 in 2006, 5.0 in 2007, 4.7 in 2008, 4.8 in 2009, 4.8 in 2010, 4.9 in 2011, 5.0 in 2012, 5.0 in 2013, 5.3 in 2014, 5.1 in 2015, 5.2 in 2016, 5.0 in 2017, 5.5 in 2018 and 5.2 in 2019

while the annual precipitation was 708 mm, 976 mm, 1039 mm, 1580 mm, 1070 mm, 948 mm, 977 mm, 1157 mm, 1082 mm, 1124 mm, 1405 mm, 1483 mm, 1202 mm, 945 mm, 907 mm, 920 mm, 932 mm, 688 mm, 979 mm, 753 mm respectively. Rainfall decreased, pH level was increased. Figure 1.2.5 shows the frequency and volume of precipitation in the three EANET sites in Korea from 2000 to 2019. pH level of Ganghwa was most frequently at pH 4.1 ~ 5.0. Imsil and Jeju showed most frequency value at pH 5.6 ~ 6.0.

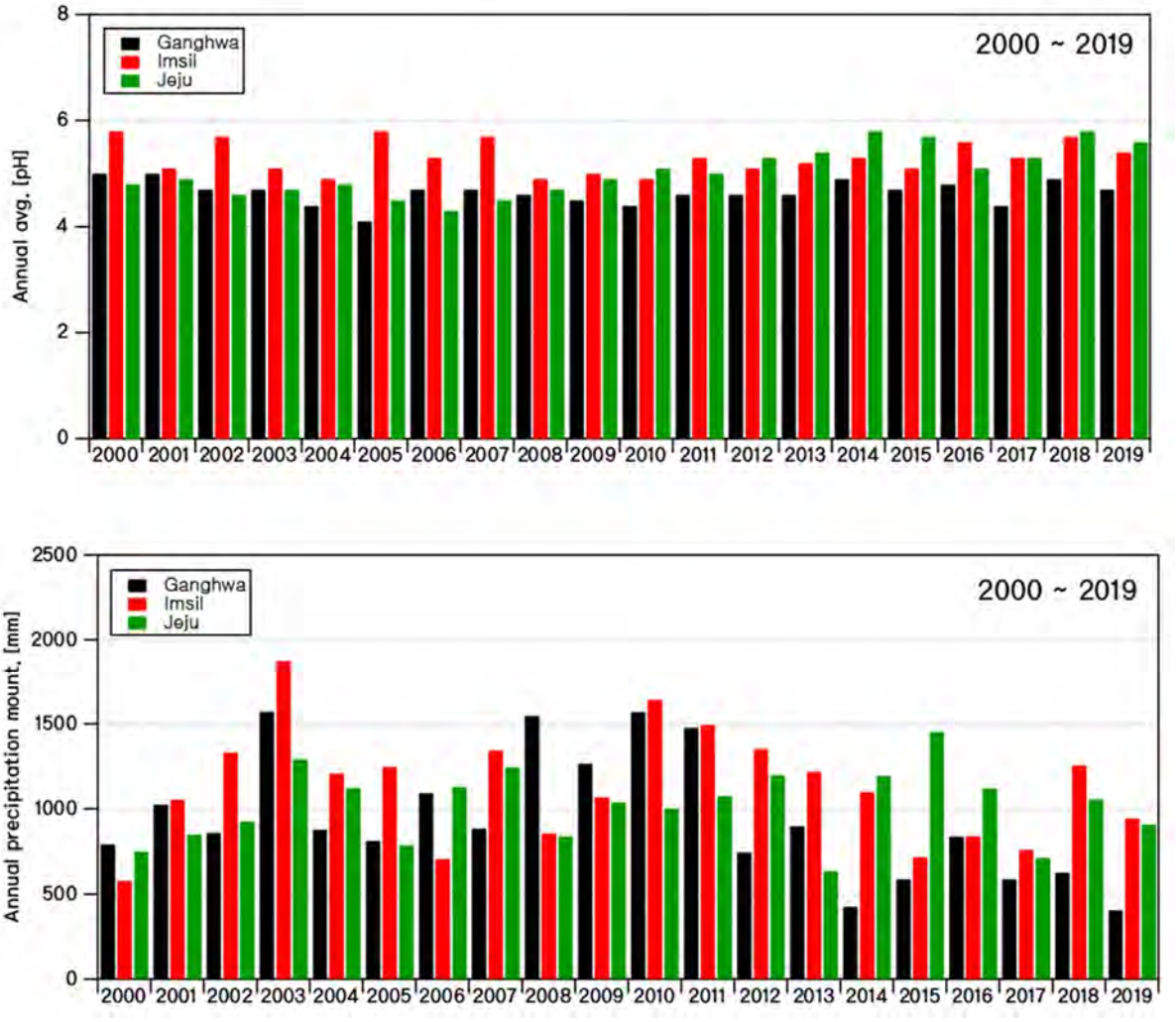

Figure 1.2.4. The annual average pH and annual precipitation mount in each site (2000 – 2019).

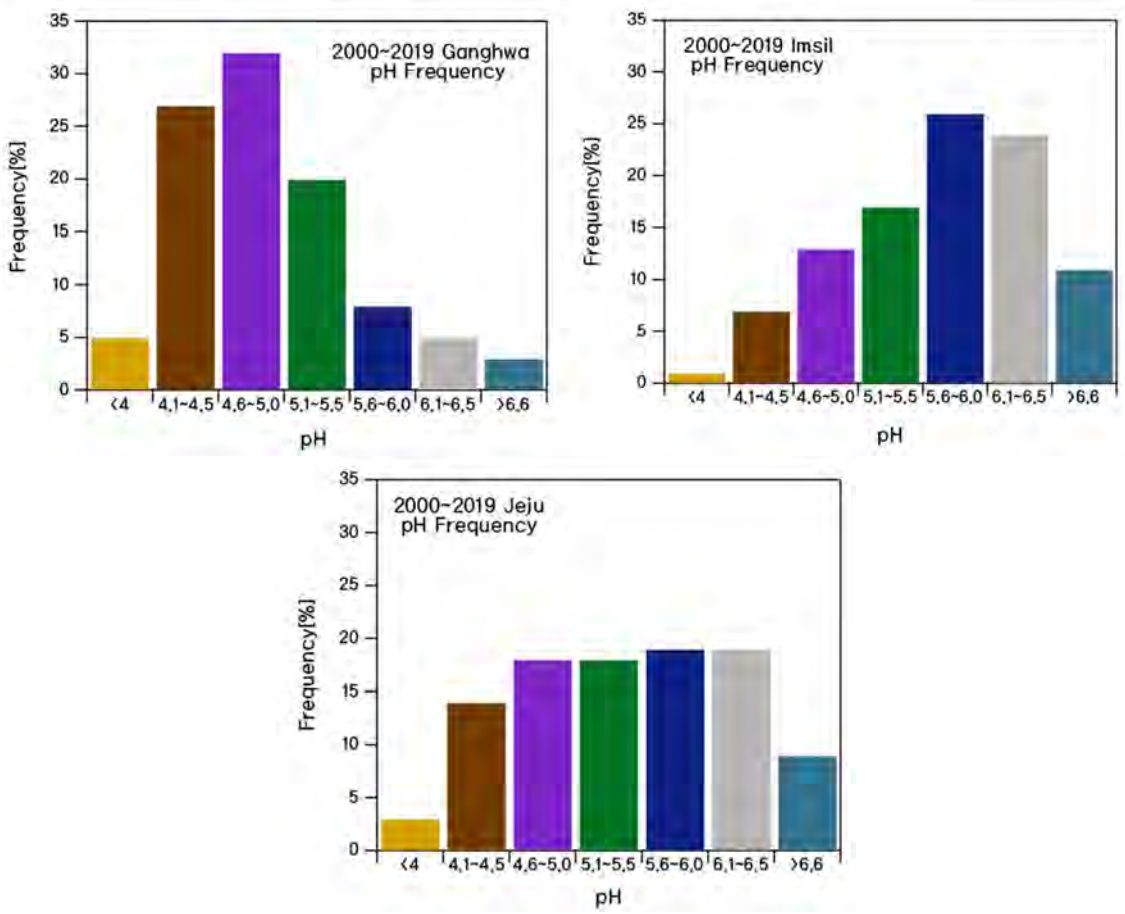

Figure 1.2.5. pH frequency and the amount in each site (2000 – 2019).

Seasonal variations of precipitation, EC, and pH are shown in Figure 1.2.6. Precipitation concentrates on summer, rainy season in Korea. In the results of the past twenty-years, summer was not always the season with the highest pH, and EC was analyzed the lowest in summer. EC concentration showed high level at the whole region in winter. And pH showed the low pH level in winter and high pH level in spring.

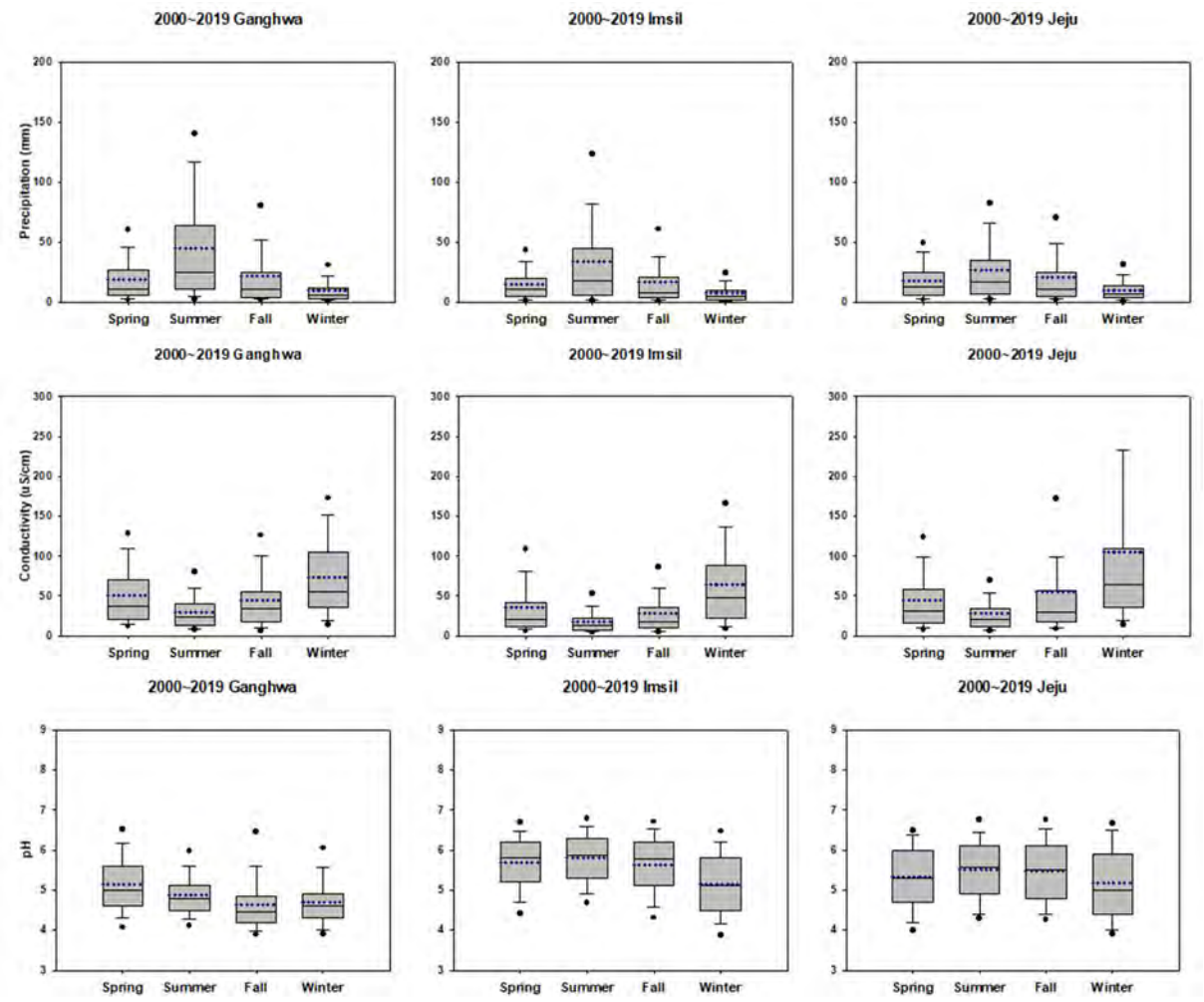

Figure 1.2.6. Seasonal variation of precipitation, electronic conductivity and pH.

Figures 1.2.7, 1.2.8, and 1.2.9 show seasonal variations of major ionic species concentrations and the amount of wet depositions at each site. The heavy precipitation during summer as discussed above diluted ionic species concentrations for rain waters, leading to the lowest concentration in summer. Despite the lowest ionic concentrations, the volume of wet depositions was still the largest in summer thanks to the heavy precipitation. The SO_4^{2-} and NO_3^- concentrations were high in winter due to high fuel demand for heating. The impact of these fuel demand was similar in Ganghwa, Imsil, Jeju. Ca^{2+} concentration in spring in Gangwha and Imsil exhibited considerable variability in spring due to Asian dust as noted earlier.

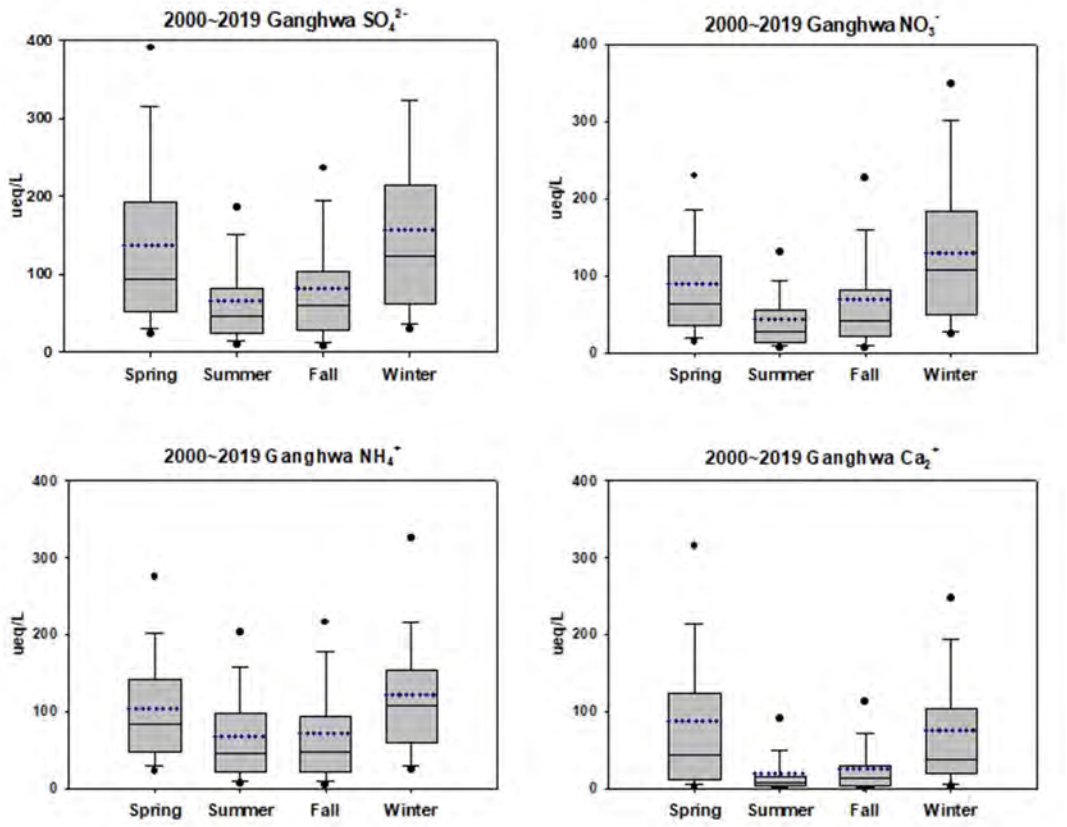

Figure 1.2.7. Seasonal variation of wet deposition (equivalent concentration), Ganghwa

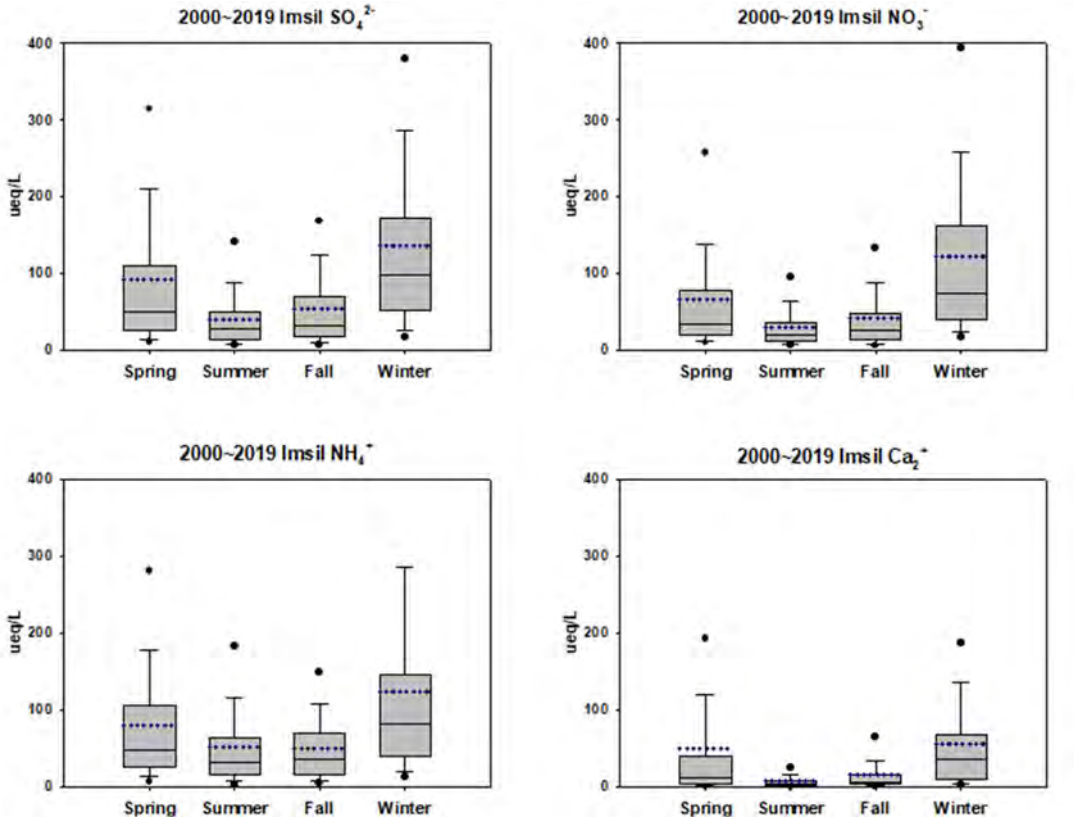

Figure 1.2.8. Seasonal variation of wet deposition (equivalent concentration), Imsil.

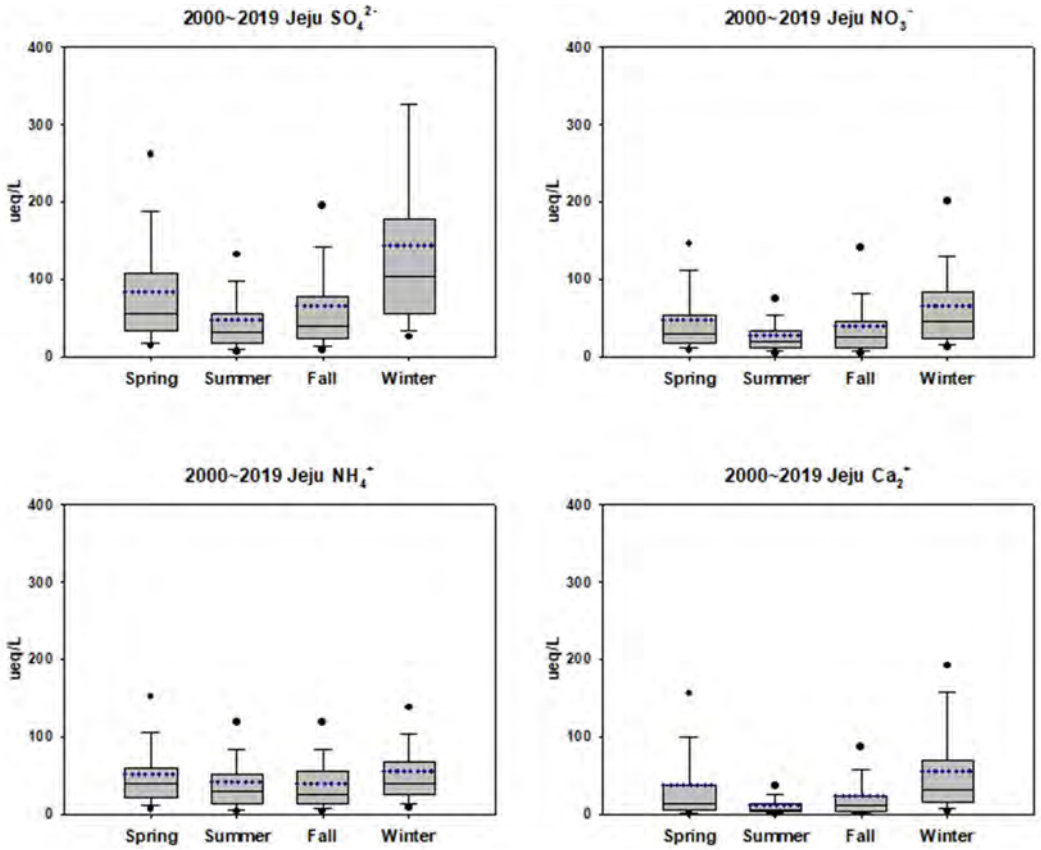

Figure 1.2.9. Seasonal variation of wet deposition (equivalent concentration), Jeju.

1.2.2 State of dry deposition

The equivalent conductance, as shown in Figure 1.2.10, was calculated using the same method for wet deposition monitoring results. The result shows that the balance between cation and anion is relatively good with 0.9525 of the coefficient of determination. In this case, based-on the review of the ion balance, samples with reliability problem were reanalyzed or excluded from data analysis.

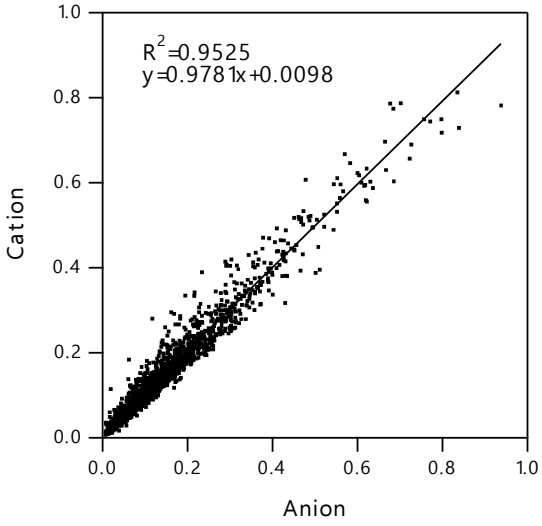

Figure 1.2.10. Relationship between total anion and cation.

Figures 1.2.11, 1.2.12, and 1.2.13 present the average monthly concentrations of SO_2, NO_2, O_3, and PM_{10} mass from 2009 to 2019. The average concentration of PM_{10} ranges from 31 μg m^{-3} to 70 μg.m^{-3}. PM_{10} concentrations were observed to be high mainly in March or May, a period of Asian dust. The average monthly concentration of O_3 measured to be high in summer. In case of SO_2, the increase trend in winter was observed. The highest concentration levels were Ganghwa island. But SO_2 and NO_2 levels were less than 0.75 ppbv and 4.16 ppbv in Jeju, one of the most remote sites, with one exception of January.

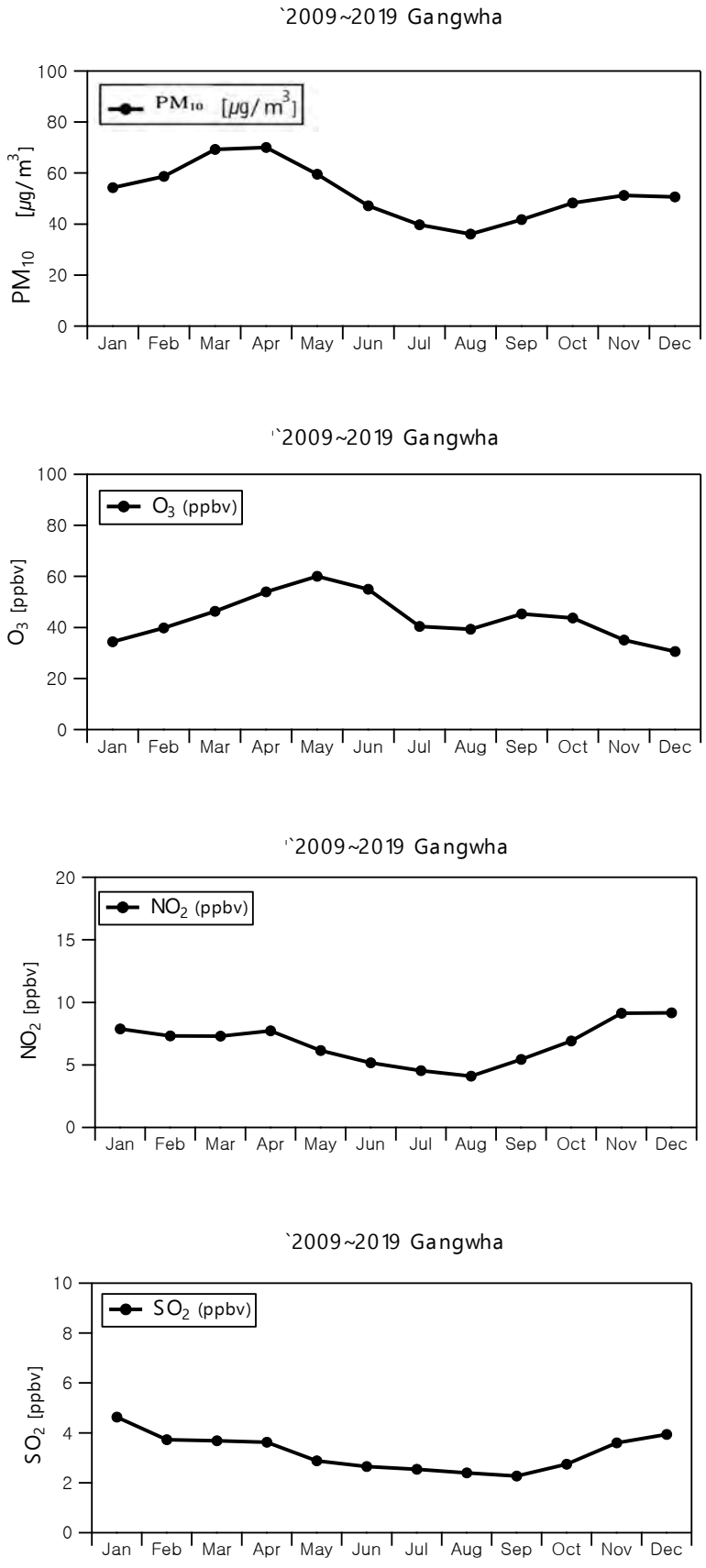

Figure 1.2.11. Average monthly concentrations of SO_2, NO_2, O_3 and PM_{10} at Ganghwa.

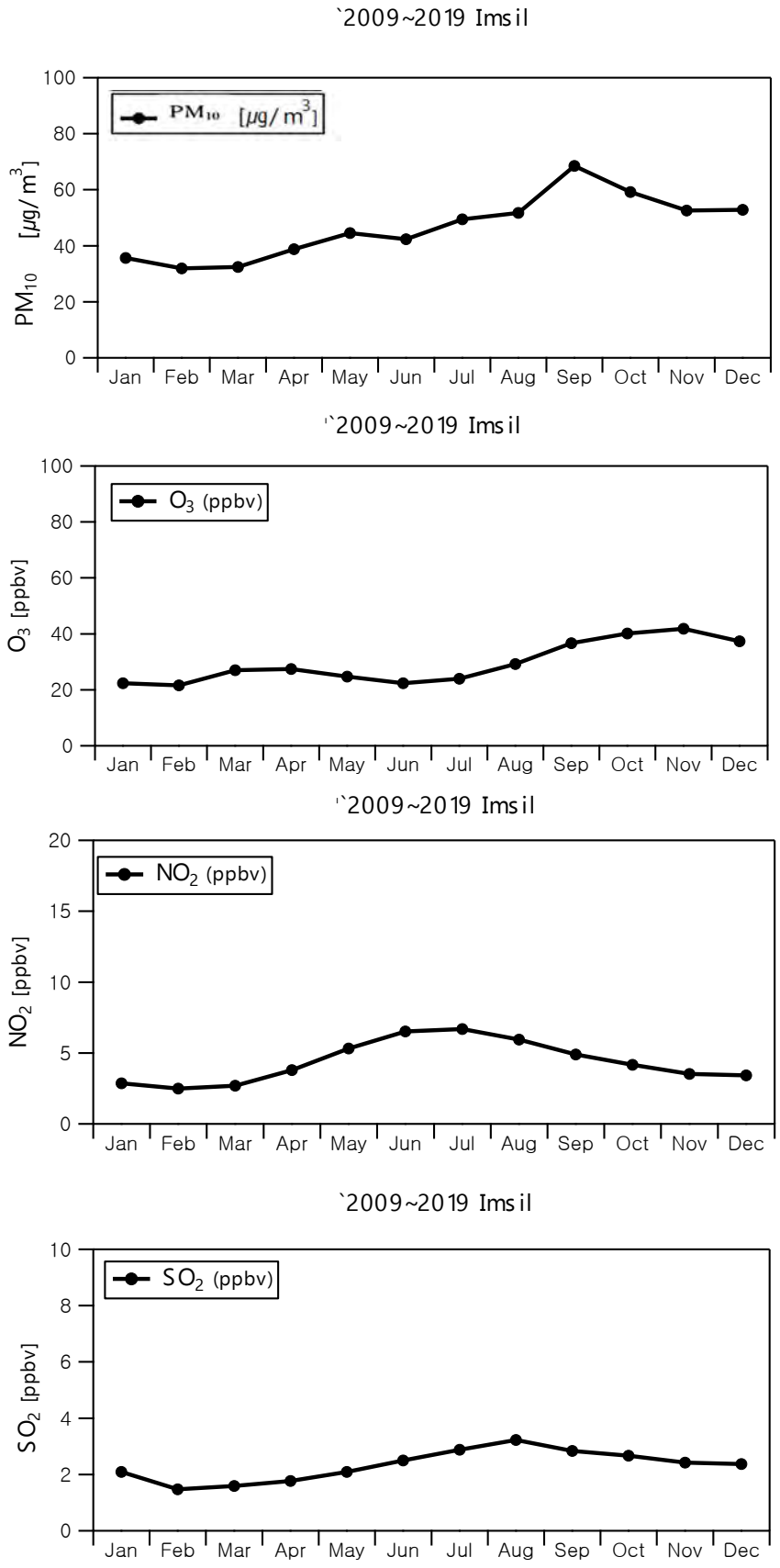

Figure 1.2.12. Average monthly concentrations of SO_2, NO_2, O_3 and PM_{10} at Imsil.

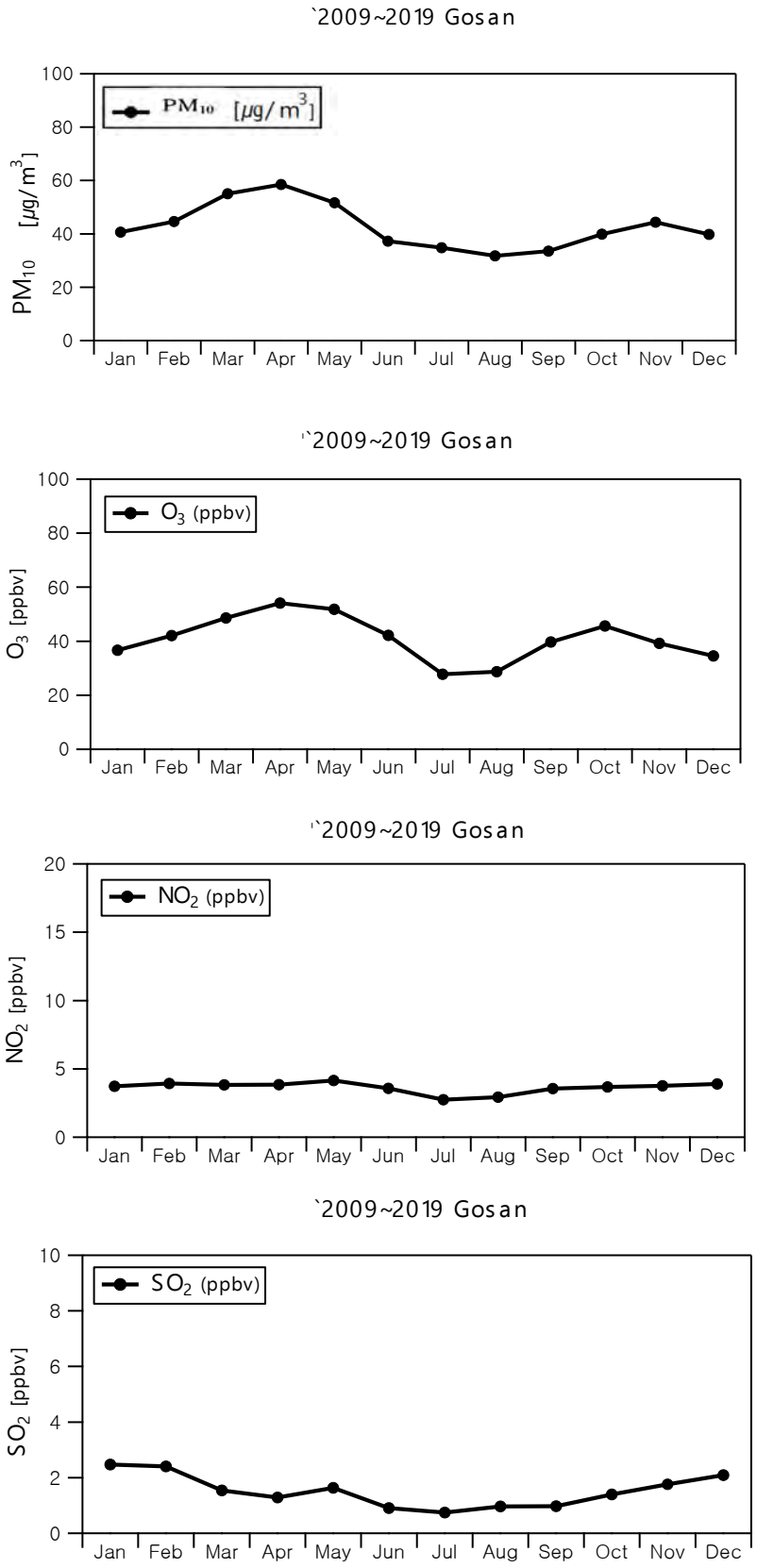

Figure 1.2.13. Average monthly concentrations of SO_2, NO_2, O_3 and PM_{10} at Jeju.

Chemical composition analysis of $PM_{2.5}$ found that SO_4^{2-} and NH_4^+ were major chemical constituents for Ganghwa, Imsil and Jeju sites. Except for Jeju, NO_3^- was significantly increased in winter. But SO_4^{2-} did not showed clear seasonal trend. As shown in Figure 1.2.14, the seasonal average concentrations of SO_4^{2-}, NH_4^+ and NO_3^- varied among the three sites and therefore this suggests there is a need for further studies to on their causes.

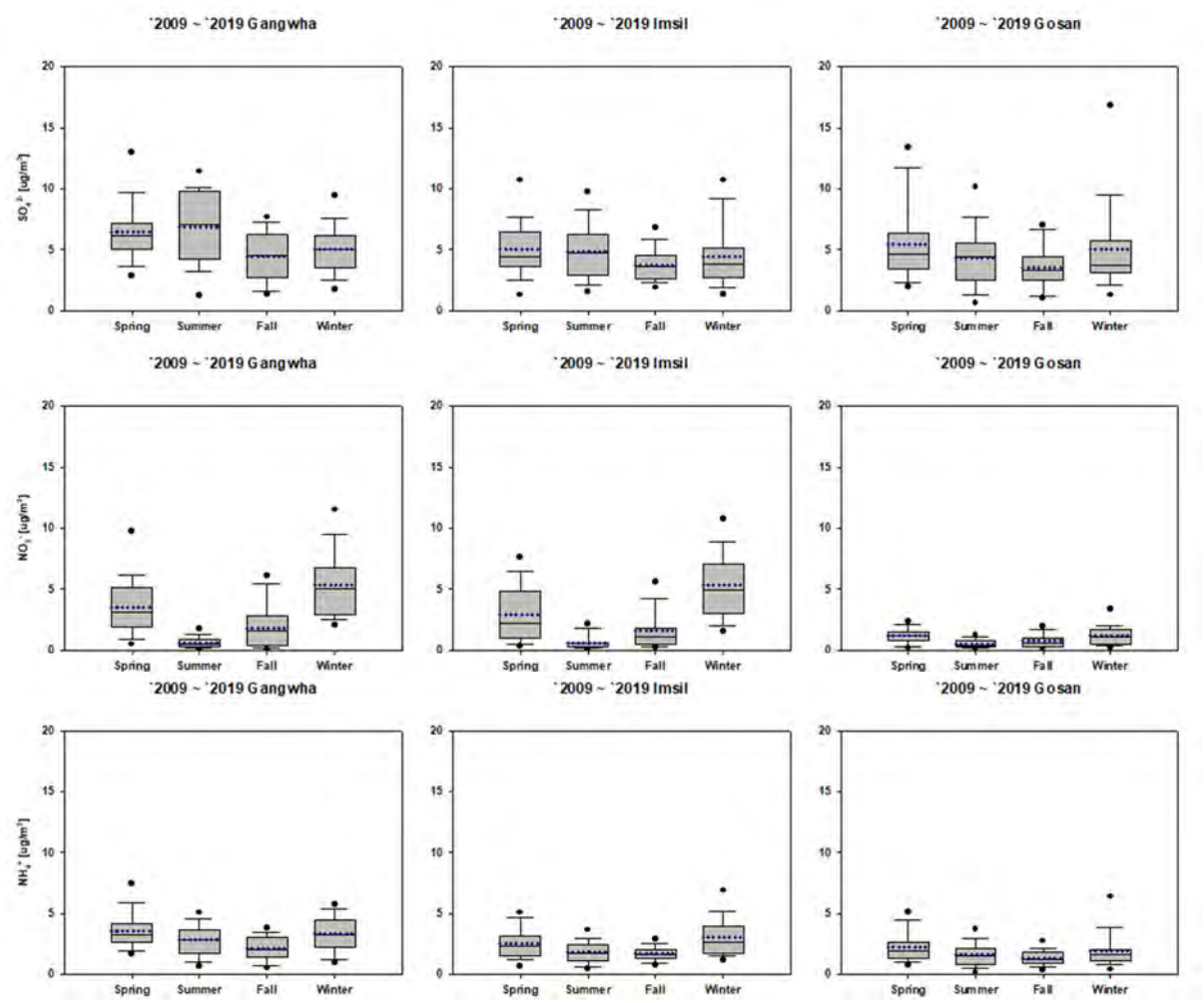

Figure 1.2.14. Seasonal variations of major chemical species concentrations in $PM_{2.5}$ at sites.

National Assessment of Acid Deposition Monitoring in Russia

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1. Basic information on National Monitoring Activities.

The investigation of acid deposition in Russia was directly stimulated by international activities in Europe. Research in scientific and monitoring areas have being related this environmental problem as well as other topics been caused by relevant large scale atmospheric pollution, its long-range transport and evident threats to land use sectors, agriculture, natural ecosystems as well as damage of materials and human life quality.

The Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET) is a governmental authority (under the Ministry of Natural Resources and Ecology) responsible for monitoring of environmental pollution in Russia including measuring precipitation chemistry and evaluating acid depositions and their effects, pollutant contamination of the atmosphere and other related environmental media as well as climate changes.

There are a large number of monitoring stations of several national networks established and operated under the umbrella of Roshydromet, and IGCE provides them various scientific and methodological supports as well as some other research institutes. The programs of some networks include the measurements of atmospheric concentrations and wet deposition of airborne pollutants. The review of national monitoring activities related to precipitation chemistry and acid deposition over the whole Asian part of Russia is presented below.

The Russian Federation has been participating in EANET activities since the preparatory phase started in 1998 with active continuation at the regular phase from 2001 (https://www.eanet.asia). Roshydromet took functions of the National Focal Point at the regular phase of EANET and has conducting all relevant monitoring and coordination activities with support of national contributors. Institute of Global Climate and Ecology (IGCE, Moscow) was designated as Russian National EANET Activity Center, and Limnological Institute SB RAS (Irkutsk) was designated as National EANET Data Center.

Russian EANET monitoring sites were established in the southeast of the Asian part of Russia, and there are additionally tens of meteorological stations owned by Roshydromet whose operations include sampling and measurement of the atmospheric deposition. Part of this network sites were

selected as WMO-GAW regional stations to provide data for global and regional assessments under the GAW as well as to trace background level of precipitation chemistry composition.

1.1. Monitoring sites

At the preparatory phase of the national EANET activities, two regions in the Asian part of Russia suitable for monitoring needs were chosen: Southeast Siberia and the Far East. During the preparatory phase, three sites were established in East Siberia (Baikal lake / Irkutsk Region), and later, at the regular phase of EANET, the one site more – in the Far East (Primorsky Kray, near Vladivostok) was established during the regular phase (Figure 1.1).

Figure 1.1. The geographical location of the Russian EANET monitoring sites.

According to the EANET methodology, four soil monitoring sites (sensitive and control) were established around (within the radius of 50 km) each sampling site of the deposition. Two objects for monitoring inland aquatic environment (one in East Siberia and another in the Far East) were also selected (Table 1.1). East Siberia is represented by three sites: Irkutsk, Listvyanka, and Mondy, which have been operating since 1998. These sites are different in physical and geographical conditions and the level of anthropogenic emission to the atmosphere.

Table 1.1 Some geographical characteristics of the Russian EANET monitoring sites

Region, site name, classification and geographical position.	Topography; landscape	Dry/wet deposition	Soil and vegetation	Inland aquatic environment
East Siberia (Irkutsk Region):				
1. Mondy (remote) ($51^0$40’ N; $101^0$00’ E; 2005 m)	Upper slope (N) of the mountain; forest	+	+	-
2. Listvyanka (rural) ($51^0$51’ N, $104^0$54’ E, 700 m)	Hilly terrain, the top of the hill; forest	+	+	+
3. Irkutsk (urban) ($52^0$14’ N; $104^0$15’ E; 400 m)	Slope (NE) of broad river valley; city.	+	+	-
Far East (Primorsky Kray)				
4. Primorskaya (rural) (43 ^{0}42’ N; 132 ^{0}07’ E; 84 m)	Low part of the mountain ridge slope; forest	+	+	+

The urban site is located in Irkutsk (52°14'N; 104°15'E), a large industrial center in the south of East Siberia, with a population of over 600,000 people. The city possesses 190 industrial and municipal boiler plants and a large Heat Power Electric Plant. The contribution of these sources is 86% of the total discharge of all atmospheric emissions of this urban area. Observations were carried out in the southern part of the city. The data obtained from this site characterize the conditions of the industrial regions of Siberia.

Listvyanka (51°51 N; 104°54 E) is a rural site located on the southwest shore of Lake Baikal 70 km southeast of Irkutsk near the source of the Angara River. The site is located beyond the Listvyanka settlement at the top of the hill, 250 m above the lake surface. The population of Listvyanka is approximately 3,000 people. In recent years, tourism has been intensely developed in this area. Several local sources of pollution are located in the settlement such as small boiler plants and stove heating. Moreover, vehicles and emissions from large regional cities such as Irkutsk and Angarsk that are situated 70 to100 km to the northwest of the settlement periodically pollute the atmosphere in this area.

Mondy (51°40'N; 101° 0'E), a remote site located in the background area (mountain area near Russian-Mongolian border), is situated on Mount Chasovye Sopki (2005 m above sea level at the plateau between the East Sayan and Khamar-Daban ridges). This area is not affected by any local sources of air pollution, being at a distance of 250 km far from industrial enterprises of the region. This site characterizes regional background conditions of the atmospheric composition and global transport of air pollutants.

Primorskaya (43° 42'N; 132° 07'E) is a rural site established in the Far East region (Primorsky Kray) in 2002 to monitor a long-range transport of pollutants through the Asian part of Russia towards the Pacific. The Primorskaya site is situated on a branch of the southern part of the Sikhote-Alin mountain range 25 km southeast of the Ussuriisk city nearby the Ussuriisky Nature Reserve.

1.2. Sampling and measurements

Wet deposition. Automatic wet-only samplers are used to collect precipitation during rainfall. However, during the winter season, an automatic wet-only sampler has low sampling efficiency (for solid snow precipitation), and, therefore, precipitation can be collected only by manual sampling. Snow, like rain, is sampled during every precipitation event. Measurement parameters of rain and snow water are the same: pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, HCO_3^-, and Cl^- (Table 1.2).

Table 1.2 Sites and monitoring parameters

Site	Monitoring environment	Frequency	Sampling method	Monitoring parameters
Irkutsk	Wet deposition	Every day	Wet only	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
	Air concentration	Weekly	Filter pack	Gases: SO_2, HNO_3, HCl, NH_3, O_3 Aerosols: SO_2, HNO_3, HCl, NH_3 Aerosols: NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
Listvyanka	Wet deposition	Every day	Wet only	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
	Air concentration	Weekly	Filter pack	Gases: SO_2, HNO_3, HCl, NH_3 O_3, Aerosols: NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
Mondy	Wet deposition	Every day	Wet only	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
	Air concentration	Weekly	Filter pack	Gases: SO_2, .HNO_3, HCl, NH_3, O_3 Aerosols: NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
Primorskaya	Wet deposition	Every day	Wet only	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
	Air concentration	Weekly	Filter pack	Aerosols: NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-
Pereemnaya River	Inland waters	Four times/year	Surface water	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^- Transparency, Water color, DOC
Komarovka River	Inland waters	Four times/year	Surface water	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, NO_3^-, Cl^-, HCO_3^- Transparency, Water color, DOC

Dry deposition. The four-stage filter pack method is used for sampling. At urban and rural sites, samples are taken weekly, and at the remote site (Mondy) – bi-weekly. Measured substances are gases (SO_2, HC1, HNO_3, and NH_3) and the water-soluble fractions of particulate matter (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, HCO_3^-, and Cl^-). Meteorological parameters such as air temperature and humidity, wind direction and velocity are observed directly at sampling sites or obtained from the nearest meteorological station.

Soil. Soil is sampled once every three to five years. Measured parameters are pH(H_2O), pH(KCl), exchangeable Na^+, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, H^+, exchangeable acidity, and ECEC.
Vegetation. Observation of tree decline, description of trees, understory vegetation survey and photographic record. Interval: every three to five years.

Inland aquatic environment. Monitoring objects are represented by two rivers: the Pereemnaya River (East Siberia) and the Komarovka River (the Far East). Measurement parameters are water temperature, pH, EC, alkalinity, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, HCO_3^-, Cl^-, transparency, water color, DOC, NO^{2-}, and PO_4^{3-}. Sampling /interval: four times per year (Table 1.2).

Two chemical laboratories analyze collected samples:

1. Laboratory of Hydrochemistry and Atmosphere Chemistry at Limnological Institute SB RAS, Irkutsk (all mandatory items) and

2. Primorsky Monitoring Center, Primorsky Department of Federal Service for Hydrometeorology and Environmental Monitoring, Vladivostok (wet deposition and surface water samples).

In Limnological Institute, the following analytical methods are used to measure ionic/elemental concentrations in precipitation, inland water, extracts from aerosols and soils: IC for anions SO_4^{2-}, Cl^- and NO_3^-; atomic absorption and flame spectrophotometry for Ca^{2+}, Mg^{2+}, Na^+, and K^+; spectrophotometry for NH_4^+. Primorsky Monitoring Center uses methods of spectrophotometry, titration and atomic absorption.

1.3 QA/QC activities

QA/QC programs are carried out at all stages of the monitoring activities. The quality of the analytical data was regularly controlled through ion balance calculations and by comparing the measured and the calculated electrical conductivities.

The laboratories are involved in the inter-laboratory comparison projects (on wet deposition, dry deposition, soil and inland aquatic environment monitoring; Reports of 1999 to 2019) organized annually by Network Center for EANET (ACAP). Other inter-laboratory comparison projects (on wet and dry deposition and inland aquatic environment monitoring) were implemented within the frame of Global Atmospheric Watch (GAW) under the umbrella of World Meteorological Organization (WMO), EMEP, ICP-Water of UNECE Convention, etc. The discrepancy between the obtained results and control values did not exceed 5 to 15%, which attested to the data validity.

2. State of acid deposition in the Asian part of Russia

2.1. Ozone

Ozone was sampled following the passive sampling method, at air monitoring sites in the south of East Siberia, and the measured concentrations were analyzed from 2016 to 2020. All of these sites meet the requirements for the remote (Mondy), rural (Listvyanka), and urban (Irkutsk) conditions (Fig. 2.1). The ozone concentrations are lower in urban areas than those in rural and background areas. The seasonal dependence of the ozone concentration was determined using its maximum (March–April) and minimum (September–October) levels.

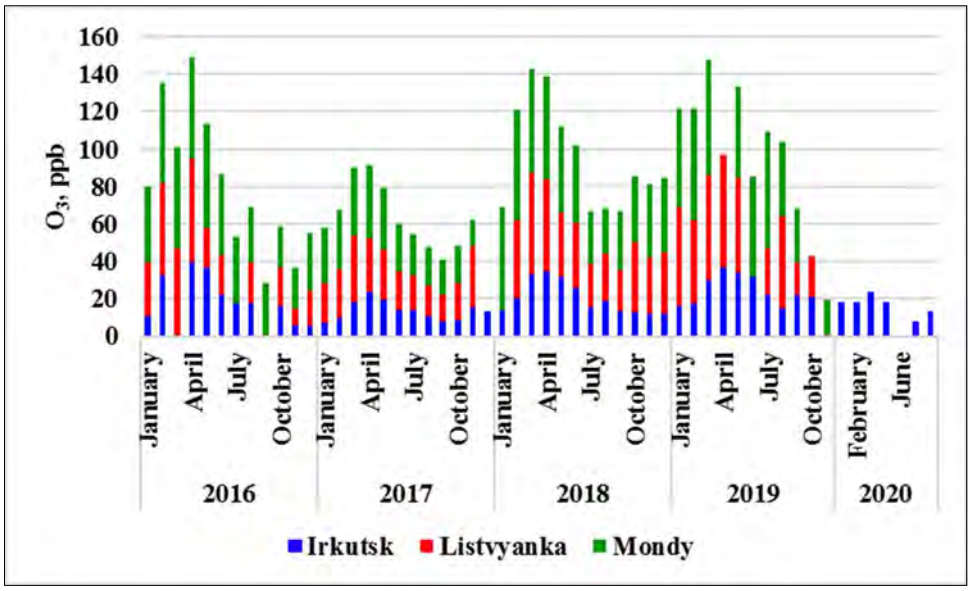

Figure 2.1. – Interannual ozone concentration dynamics at the Irkutsk, Listvyanka and Mondy monitoring sites sampled by the passive sampling method from 2016 to 2020.

According to Figure 2.1, at the Irkutsk site during the spring maximum period, the ozone concentration reaches (≈40 ± 10) ppb; however, during the autumn minimum, this concentration drops to (≈10 ± 2) ppb. The main cause of the low ozone concentration under urban conditions may be the increased sink in the atmosphere due to the oxidation of anthropogenic gases.

At sites Mondy and Listvyanka, a similar seasonal ozone concentration pattern is observed, with higher concentrations in the rural and remote areas than those in the city. This is due to the remote location of the sites from the industrial centers of the region and the orographic features of the terrain. In the cold season, episodic sharp drops in O_3 are observed in the surface atmosphere at site Listvyanka. Based on the automatic records of the ozone concentrations, during the northwesterly transport of polluted air masses from the industrial centers of the Baikal region to the southern basin of Lake Baikal, the ozone concentrations in the atmosphere drop to zero due to oxidation by pollutants such as SO_2 and NO_x (Kholyavitskaya et al., 2011; Khuriganova et al., 2016, 2019).

2.2. Air concentration (aerosols)

The stationary sources, including the enterprises of the fuel and energy complex, chemical, metallurgical, pulp and paper industries and the production of building materials, make the main contribution to the pollution of the air basin in the Baikal region (State Reports, 2008-2020). As Fig. 2.2 illustrates, in contrast to the relatively stable flow of gross matter into the atmosphere from stationary and mobile sources between 2000 and 2019, the area of the burnt forest increased significantly from 2014 to 2019. The release of forest combustion products (gases, soot and aerosol) into the atmosphere affects not only the air quality but also the optical and microphysical characteristics of the atmosphere (Kozlov et al., 2014; Khodzher et al., 2019; Golobokova et al., 2018a, 2020).

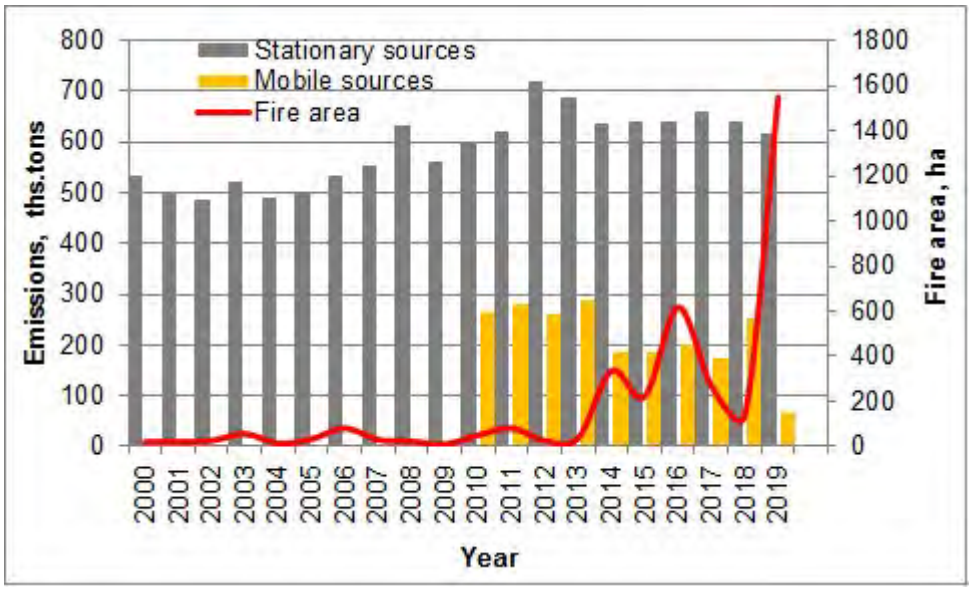

Figure 2.2. Interannual variability of total emissions into the atmosphere from stationary and mobile sources within the Irkutsk Region (thou tons per year) and the average area of single wildfire (ha) (State Reports, 2008-2020).

Figure 2.3 shows interannual dynamics of the average concentrations of the total amount of ions in aerosol for different periods from 2000 to 2019. Table 2.1 presents the ratio of the concentrations of the average annual total amounts of ions from 2000 to 2005 to later periods.

Table 2.1 Variability in the ratio of the average total amount of ions in aerosol from 2000 to 2005 to the total amount of ions in followed observation periods at the EANET monitoring stations in Russia

Station	2000-2005 2006-2009	2000-2005 2010-2014	2000-2005 2015-2019
Irkutsk	1.2	1.4	1.7
Listvyanka	2.1	2.7	3.2
Mondy	2.1	2.1	1.9
Primorskaya	0.8	0.8	1.8

It is obvious from Table 2.1 that three stations in East Siberia (Baikal region) are characterized by a decrease in the total content of ions from 2000 to 2019. The highest interannual variability in the total amount of ions in aerosol was observed at the rural station Listvyanka. At station Primorskaya (Primorsky Kray), the ionic concentrations in aerosol increased until 2007. Although the average interannual concentrations of ions between 2010 and 2014 were higher than between 2002 and 2006, since 2007, they have been steadily decreasing at this station (Fig. 2.3). The lowest ionic concentrations in aerosol, without a significant interannual variability, were determined at the background station Mondy.

Seasonal dynamics of the concentrations of major ions in aerosol at stations Irkutsk, Listvyanka and Primorskaya are typical of the continental sites, with an increase in the concentrations in the cold season and the minimum values in the warm season. Despite this, in some summer months, individual ions increased in aerosol (Fig. 2.4 *A, B, D*). Due to climate warming raised in Siberia too, the wildfires, especially in combination with such harmful meteorological phenomena as high air temperatures ("heat waves") or dust storms, are becoming one of the main sources of air pollution in summer (Khodzher et al., 2019; Golobokova et al., 2018a).

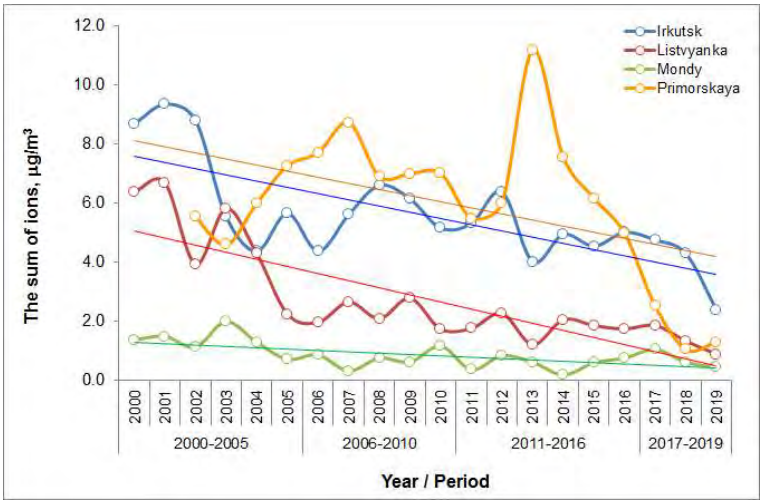

Figure 2.3. Interannual dynamics of the concentrations of the total amount of ions in the atmospheric aerosol at the EANET monitoring stations Irkutsk, Listvyanka, Mondy, and Primorskaya from 2000 to 2019.

In the absence of wildfires, underlying surface and anthropogenic activity remain the main sources affecting an increase in pollutants in the atmosphere. Near station Listvyanka, unlike stations Irkutsk and Primorskaya, there was no significant seasonal dynamics in the ionic concentrations of aerosol (Fig. 2.4 *B*). This is owing to the absence of large pollution sources in the area of this station and the constant cleaning of the atmosphere near the large water body (Lake Baikal) from aerosol particles by precipitation, mists and dry deposition.

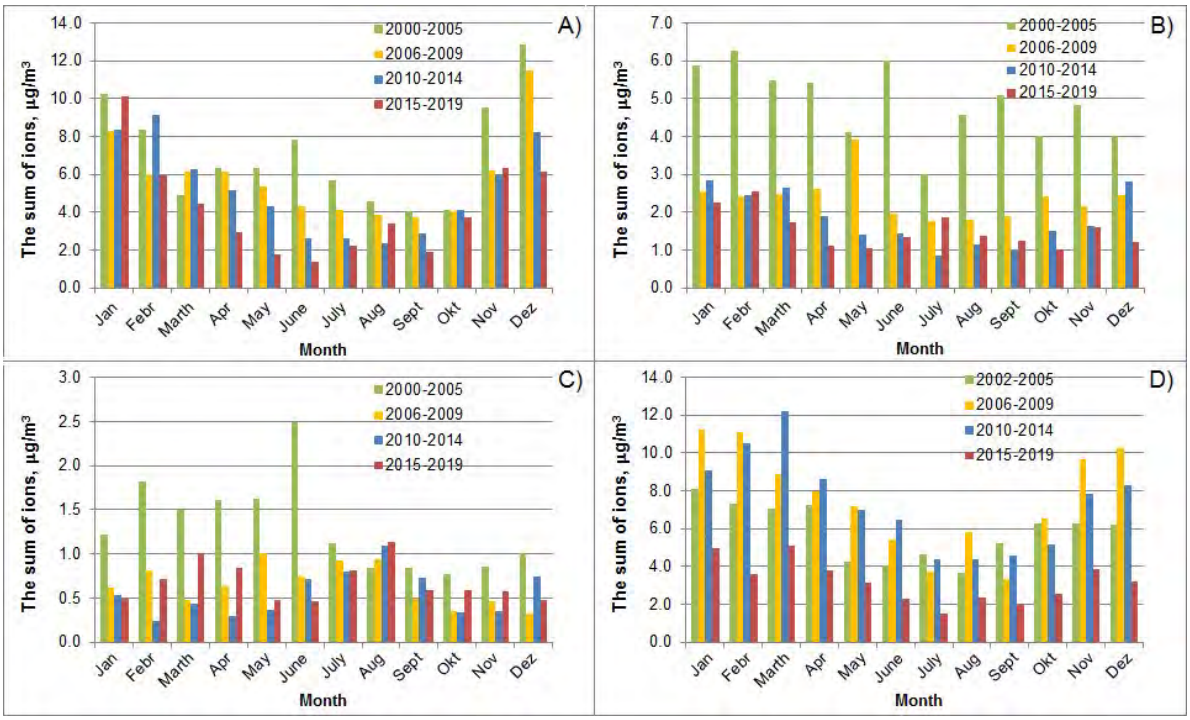

Figure 2.4. Seasonal dynamics of the concentrations of the total amount of major ions in aerosol at the EANET monitoring stations for different 5-year periods at: *A* - Irkutsk, *B* - Listvyanka, *C* - Mondy, and *D* - Primorskaya.

At station Mondy, with the relatively stable ionic concentrations throughout the year, they slightly increased in winter, spring, and summer. Here, the main source of aerosol is soil. This tendency was traced over the entire observation period, except for the interval between 2000 and 2004 when construction was carried out at the station, due to which terrigenous material was intensively released into the atmosphere (Fig. 2.4 *C*).

At station Irkutsk, the concentrations of NH_4^+, Ca^{2+} and SO_4^{2-} mainly predominated from 2000 to 2009. Recently, there has been some increase in the proportion of Na^+ and Cl^- in winter and during snowmelt (from February to April) (Fig. 2.5). The growth of these ions in aerosol is associated with the local source such as treatment of the city's roads with salt during the cold season (Golobokova et al., 2018b).

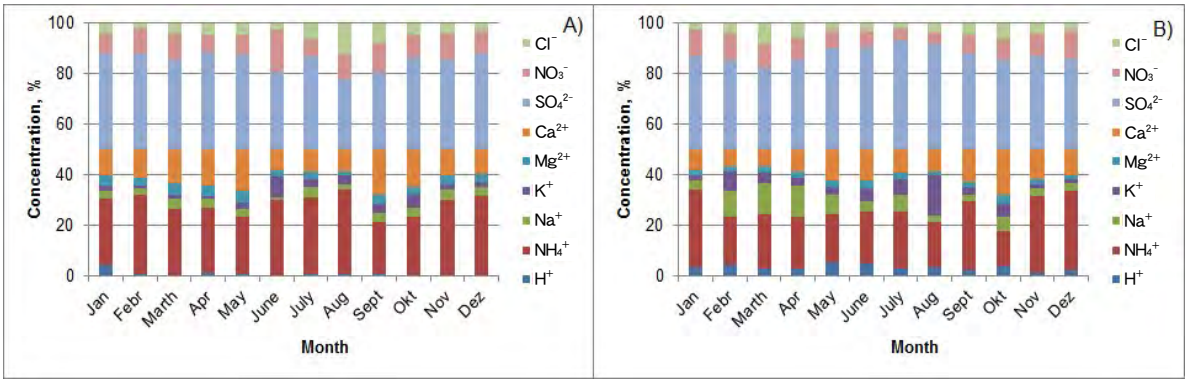

Figure 2.5. Seasonal dynamics of the average annual concentrations of major ions in aerosol at station Irkutsk from 2000 to 2005 (A) and from 2015 to 2019 (B).

In summer, the proportion of the K^+ ions increased in aerosol (July and August), indicating the influx of smoke aerosol from wildfires. Depending on the type of biomass burning, volatile inorganic components condense into a group of particles enriched in potassium (Reid et al., 2005; Urbanski et al., 2009).

At station Listvyanka, in the initial observation period (from 2000 to 2005), NH_4^+ and SO_4^{2-} were major ions in the aerosol composition (Fig. 2.6). In subsequent years, the aerosol composition has changed: the proportion of H^+ has increased, especially in winter due to insufficient amount of other alkaline components. In summer, like in Irkutsk, the proportion of K^+ increased.

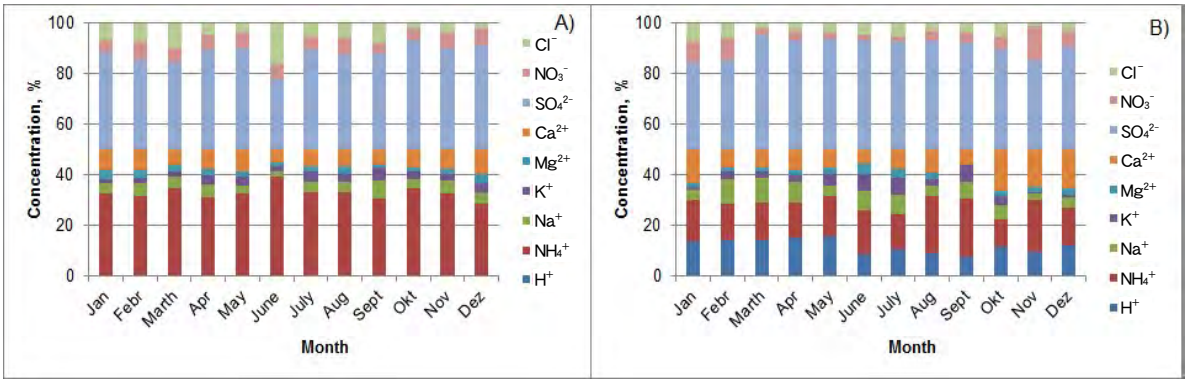

Figure 2.6. Seasonal dynamics of the average annual concentrations of major ions in aerosol at station Listvyanka from 2000 to 2005 (*A*) and from 2015 to 2019 (4).

The highest variability in the chemical composition of aerosol over the entire observation period (from 2000 to 2019) was observed at station Mondy (Fig. 2.7).

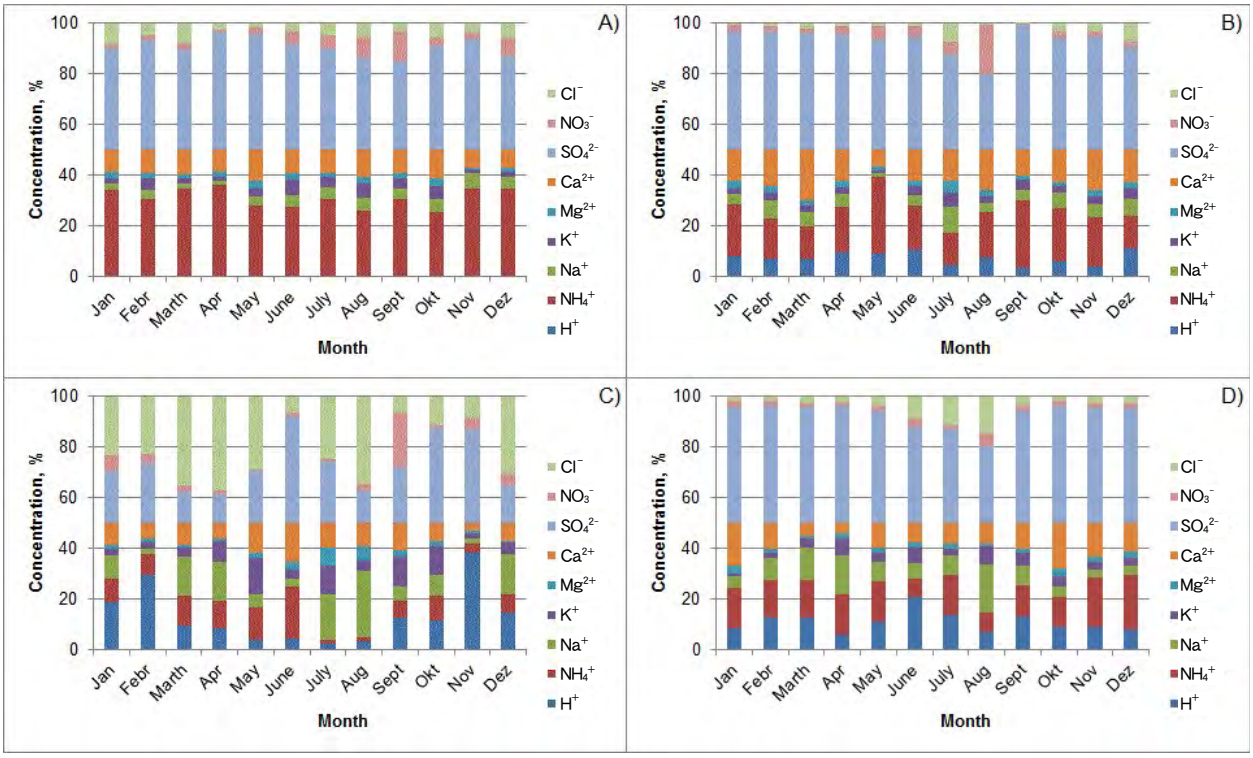

Figure 2.7. Seasonal dynamics of the average annual concentrations of major ions in aerosol at station Mondy from 2000 to 2005 (*A*), from 2006 to 2009 (*B*), from 2010 to 2014 (*C*), and from 2015 to 2019 (*D*).

At station Mondy, like in Irkutsk, the major ions from 2000 to 2006 were NH_4^+, Ca^{2+} and SO_4^{2-} (Fig. 2.7 *A*). From 2006 to 2009, there were changes in the cation composition; the proportion of Ca^{2+} increased; the role of NH_4^+ decreased, and the proportion of the H^+ ions increased significantly (Fig. 2.7 *B*). The highest variability in the aerosol composition at station Mondy manifested from 2010 to 2014 when the proportions of SO_4^{2-}, Cl^-, Na^+, and K^+ increased (Fig. 2.7 *C*). Semi-desert and desert areas of Mongolia can be the sources of these ions where the frequency of dust storms has increased in recent years. A decrease in the amount of precipitation and soil moisture, degradation of vegetation, as well as overgrazing of animals, led to the desertification of this area (Jugder et al., 2011; Lee and Sohn, 2011). From 2015 to 2019, at station Mondy, SO_4^{2-} dominated anions, and the proportion of NH_4^+, Na^+, Ca^{2+} and H^+ was high in the cations.

At station Primorskaya, the chemical composition of aerosol changed from 2015 to 2019 when Na^+, Ca^{2+}, SO_4^{2-} and NO_3- became major ions (Fig. 2.8). In the previous observation period (from 2000 to 2014) NH_4^+ and SO_4^2 predominated.

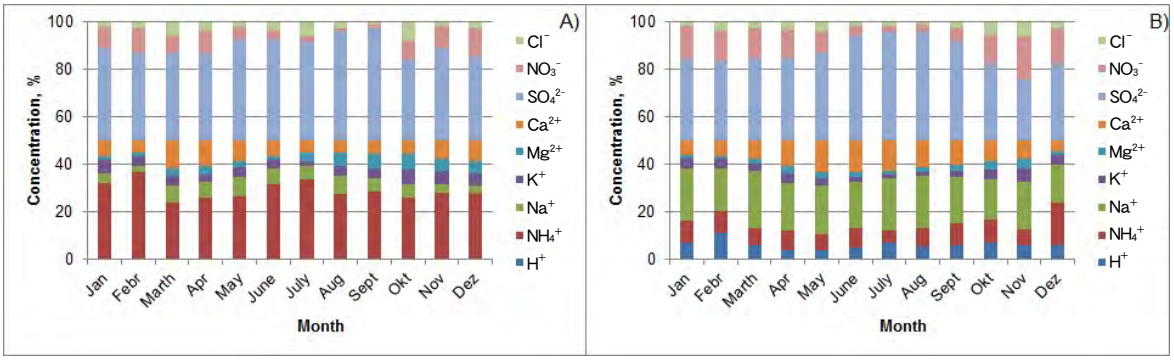

Figure 2.8. Seasonal dynamics of the average annual concentrations of major ions in the atmospheric aerosol at station Primorskaya from 2002 to 2005 (A) and from 2015 to 2019 (B).

SO_2, NH_3 and HCl had the highest concentrations among gaseous air pollutants in Irkutsk. The concentrations of SO_2 increased in 2005 and 2006, as well as from 2009 to 2013, when winters were the coldest. In recent years, the SO_2 concentrations at the urban site have been decreasing. The highest HCl concentrations were observed between 2015 and 2018. The concentration of NH_3 is the least variable at station Irkutsk, although its presence in the atmosphere plays a significant role in the regulation of acid deposition.

The concentrations of gaseous pollutants at station Listvyanka, like in Irkutsk, increased from 2009 to 2013, and since 2016, they have been decreasing. At station Primorskaya, like at the monitoring stations in the Baikal region, the concentrations of HCl, NH_3 and SO_2 increased from 2009 to 2013, and in subsequent years, they have been decreasing.

Fluctuations in winter air temperatures towards warming may cause the changes in the concentrations of gaseous pollutants and in the aerosol composition of the atmosphere at all monitoring stations, which entails a decrease in the volumes of burning fuel, mainly coal, and, hence, emissions of pollutants into the atmosphere. At the same time, climate warming in East Siberia is much faster than in other Russian regions, which affects a decrease in the amount of precipitation, moistening and water runoff of rivers and increases the number and area of wildfires that pollute the atmosphere (Sinyukovich and Chernyshov, 2019).

2.3. Dry deposition

The assessment of the intake of pollutants from the atmosphere is one of the criteria of the ecological condition of various natural environments. Sulphur and nitrogen coming in large amounts from the atmosphere onto the underlying surface lead to acidification of surface waters and soil as well as oppression and death of forests and other natural objects. In the Baikal region, the acidification of precipitation has become the most likely unfavourable effect of the transport and deposition of sulphur and nitrogen, leading to a shift in the balance of major ions in the waters of the tributaries of the southern basin of Lake Baikal (Obolkin et al., 2016).

Sulphur and nitrogen fluxes from the atmosphere during dry deposition were recalculated for

nitrogen from nitrates and ammonium ions, and for sulphur from sulfate. The influx of nitrogen with gases was calculated from the total amount of gaseous pollutants, HNO_3 and NH_3, and that of sulphur – from SO_2. For calculations, the following formula was used: $D=C \bullet V \bullet \Delta t$, where D is the influx of substances, C – the average concentration for period Δt, and V – the dry deposition velocity (EANET, 2010).

The influx of pollutants from the atmosphere to the underlying surface at the Russian monitoring stations was calculated for the period from 2000 to 2019 (Fig. 2.9). At all stations, between 2014 and 2019, the uptake of sulphur from the atmosphere with gases was higher than with aerosol (Fig. 2.9). A similar distribution in the influx of substances during dry deposition was documented previously (Golobokova et al., 2007; Obolkin et al., 2016).

In East Siberia (Baikal region), from 2012 to 2014, at stations Irkutsk, Listvyanka and Mondy, sulphur and nitrogen fluxes with aerosol decreased, which continued in 2018 and 2019, and in 2016 and 2017, it averaged from 12 to 58% for nitrogen and from 22 to 39% for sulphur. There was a similar decrease in sulphur fluxes with gaseous pollutants, which amounted to almost 50% in Irkutsk, 48% in Listvyanka and 67.5% in Mondy. In recent years, at the urban Irkutsk site, nitrogen fluxes with gases have increased by 3%, although at other sites, their influx has decreased by 11% in Mondy and by 40% in Listvyanka (Fig. 2.9 *A*-*C*). At station Primorskaya (Fig. 2.9 *D*), there was a steady tendency towards a decrease in the influx of substances with aerosol, despite the significant fluctuations in the dynamics of the nitrogen and sulphur influx with gases. The factors that determine the change in fluxes of substances to the underlying surface at the EANET monitoring stations are as follows: orographic heterogeneities of the underlying surface, economic activity, climate change, wildfires, etc.

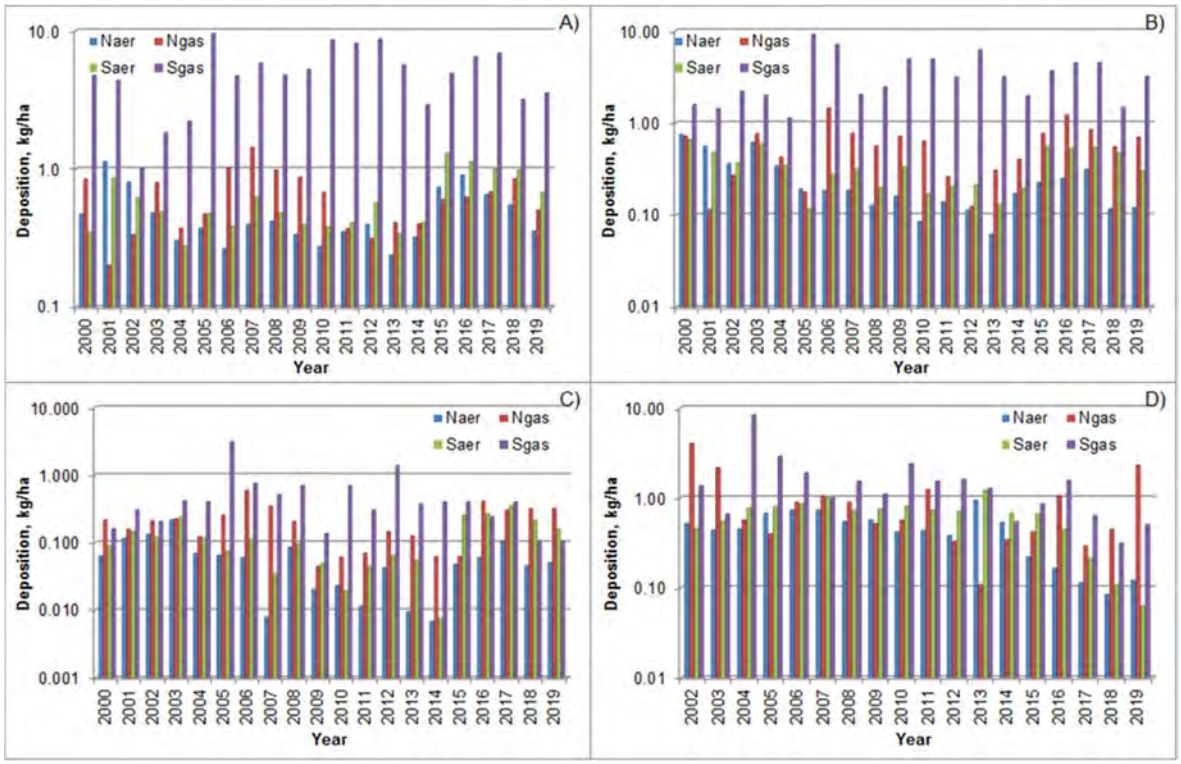

Figure 2.9. Sulfur and nitrogen fluxes during dry deposition at the monitoring stations: *A* - Irkutsk, *B* - Listvyanka, *C* - Mondy, and *D* - Primorskaya, kg/ha.

3. Wet deposition

3.1 Composition of precipitation

At the Russian EANET monitoring stations, the highest mineralization in the precipitation composition, as previously, was recorded at station Irkutsk (Fig. 3.1). From 2015 to 2019, the total ionic concentration (sum, $\sum_i$) in Irkutsk was on average 5 times higher than at the background station Mondy and 1.6 times higher than at station Primorskaya. The total amount of ions in precipitation at stations Irkutsk and Mondy tended to decrease from 2015 to 2019. At stations Listvyanka and Primorskaya, the total amount of ions changed little over five years of observations.

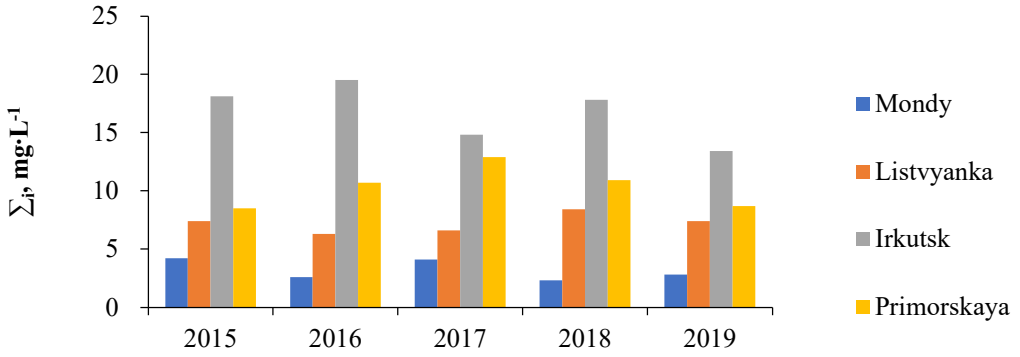

Figure 3.1. Average annual variations (from 2015 to 2019) of TDS in precipitation at the EANET monitoring stations Irkutsk, Listvyanka, Mondy, and Primorskaya.

At all monitoring stations, except for Primorskaya, Ca^{2+} and SO_4^2 were the main components in the chemical composition of precipitation (Fig. 3.2). At Primorskaya station, from 2015 to 2019, the proportion of the NH_4^+ ions in precipitation was on average higher than Ca^{2+}. From 2014 to 2019, in contrast to the previous observation period (from 2010 to 2014), the concentrations of Cl^-, and NH_4^+ increased. The relative concentrations of Cl^-, Na^+, K^+, and Mg^{2+} in the precipitation were maximum at this station. In Listvyanka, like in previous years, the higher contribution to the total concentration of salts in precipitation was from SO_4^{2-}, NO_3^- and H^+. Irkutsk was characterized by the maximum values of SO_4^{2-} and Ca^{2+} in the ionic composition of precipitation. At station Mondy, HCO_3^- and NH_4^+ predominated in precipitation.

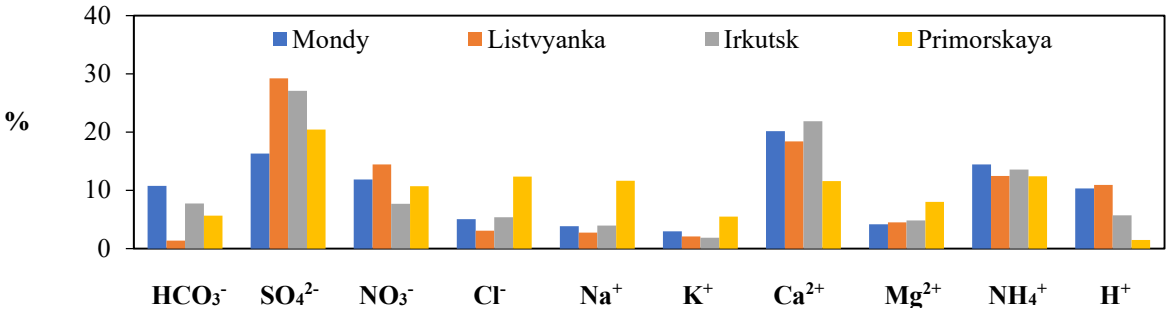

Figure 3.2. Average annual variations (from 2015 to 2019) in the relative ionic concentrations of precipitation at the EANET monitoring stations Irkutsk, Listvyanka, Mondy, and Primorskaya.

Table 3.1 presents the data of the ionic composition of precipitation with interannual dynamics. At stations Irkutsk and Mondy, the average annual concentrations of most ions in precipitation decreased from 2015 to 2019, and at station Primorskaya, the concentrations of some ions increased. This, at station Irkutsk the concentration of Cl^- decreased by 50%, SO_4^{2-} – by 35% and NH_4^+ – by 30%, and at station Primorskaya, the concentration of Ca^{2+} increased by 28%, and Na^+ – by 26%. At this station, only the concentration of SO_4^{2-} increased most significantly (by 32%).

Comparison of the chemical composition of precipitation at the monitoring stations revealed the maximum values of Na^+, K^+ and Cl^- in the precipitation of station Primorskaya, NO_3^- in the precipitation of station Listvyanka as well as Ca^{2+} and SO_4^2 in the precipitation of station Irkutsk. At all stations, except for the background station Mondy, despite the different anthropogenic pressure, the concentrations of NO_3^-, unlike most of other components in the ionic composition of precipitation, were almost the same. Figure 3 shows the seasonal dynamics of the monthly weighed average concentrations of acidifying components in precipitation at the stations. The highest concentrations of SO_4^{2-}, NO_3, and NH_4^+ were recorded in spring (March and April) when the amount of precipitation is low (4 to 9% of their annual amount), and the atmosphere is polluted due to snowmelt and intensification of wind speed during this period of the year.

Table 3.1 The chemical composition of precipitation at the EANET monitoring stations, mg·L^{-1}

Year	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+
Irkutsk									
2015	2.55	7.27	1.74	1.75	0.73	0.27	2.71	0.24	1.50
2016	2.99	7.28	2.00	1.38	0.84	0.57	2.96	0.38	1.05
2017	3.17	4.92	1.75	0.94	0.51	0.29	2.32	0.27	0.66
2018	4.37	5.82	1.71	0.96	0.55	0.37	3.22	0.42	0.66
2019	2.42	4.74	1.66	0.89	0.50	0.33	1.91	0.24	0.73
Av.	**3.10**	**6.01**	**1.77**	**1.18**	**0.63**	**0.37**	**2.62**	**0.31**	**0.92**
Listvyanka									
2015	0.11	3.35	1.69	0.28	0.15	0.20	0.83	0.12	0.74
2016	0.39	2.30	1.93	0.16	0.13	0.15	0.76	0.10	0.38
2017	0.13	2.83	1.96	0.16	0.12	0.17	0.85	0.13	0.38
2018	0.39	3.21	2.19	0.20	0.13	0.18	1.20	0.17	0.36
2019	0.23	2.90	2.10	0.25	0.16	0.26	0.89	0.14	0.43
Av.	**0.25**	**2.92**	**1.97**	**0.21**	**0.14**	**0.19**	**0.91**	**0.13**	**0.46**
Mondy									
2015	1.56	0.78	0.37	0.18	0.06	0.23	0.52	0.08	0.30
2016	0.87	0.50	0.41	0.10	0.05	0.07	0.44	0.04	0.13
2017	0.57	1.08	0.99	0.27	0.10	0.11	0.59	0.07	0.31
2018	0.66	0.47	0.37	0.10	0.06	0.07	0.26	0.03	0.19
2019	0.66	0.67	0.60	0.10	0.09	0.05	0.33	0.03	0.24
Av.	**0,86**	**0,70**	**0,55**	**0,15**	**0,07**	**0,11**	**0,43**	**0,05**	**0,23**
Primorskaya									
2015	0.82	3.03	1.70	1.04	0.78	0.39	0.77	0.21	0.67
2016	1.19	3.51	1.99	1.46	0.96	0.79	0.91	0.23	0.74
2017	1.41	4.20	2.35	1.74	0.85	0.61	1.20	0.37	1.16
2018	1.90	4.24	1.73	0,97	0.77	0.54	0.88	0.31	1.11
2019	0.90	2.19	1.64	1.37	0.58	0.42	0.65	0.25	0.71
Av.	**1.24**	**3.43**	**1.88**	**1.40**	**0.79**	**0.55**	**0.88**	**0.27**	**0.88**

The lowest concentrations of SO_4^{2-} and NO_3^- were determined in precipitation of the warm season (from June to September) when the emissions from heat power plants decreased, and the amount of precipitation of the annual rate increased (60-70%) (Fig. 3.3). In contrast to other ions, the concentrations of NH_4^+ were maximum in spring and summer (Fig. 3.3) when many of its sources

appeared (wildfires, decomposition of plant materials, etc.).

As previously, during the observation period, the lowest pH values were observed in precipitation at station Listvyanka (Fig. 3.4). Interannual variations in this parameter at this station were insignificant, with the average annual value of 4.80±0.06 for five years of observations. At station Irkutsk, pH was slightly higher, 4.95±0.14, and at the background station Mondy, pH was 5.34±0.09. The highest pH values, 5.50±0.23 on average, were determined in precipitation at station Primorskaya. In East Siberia (Baikal region), the acidity of precipitation tended to increase from 2015 to 2019. At station Primorskaya, on the contrary, the acidity of precipitation decreased.

In the seasonal dynamics, the minimum pH values at the stations of the Baikal region were observed in the period of the maximum precipitation, from June to August, and in the Primorsky Kray – from October to November. The maximum pH values of precipitation at stations Mondy and Irkutsk were determined in February, at station Listvyanka – in November, and at station Primorskaya – in January (Fig. 3.5).

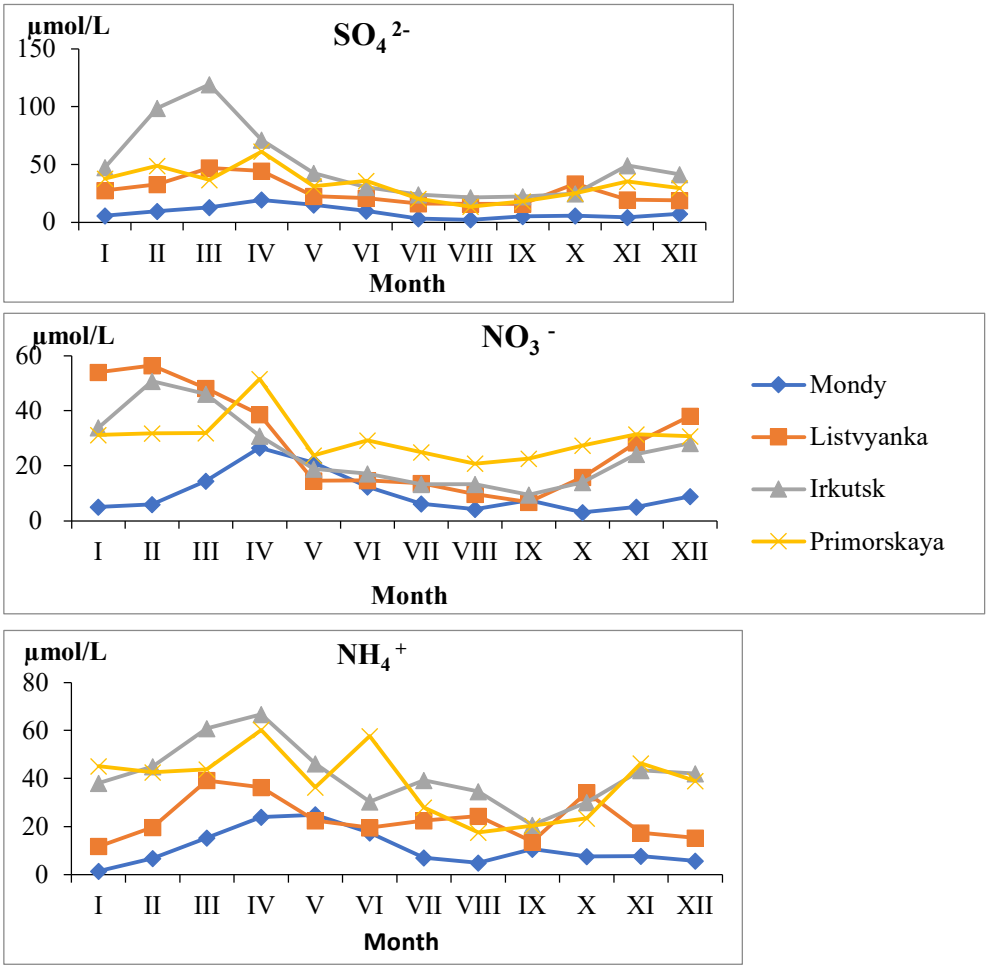

Figure. 3.3. Seasonal variation (from 2015 to 2019) in the amount-weighted average concentrations of ions in precipitation at the EANET monitoring stations, µmol/L.

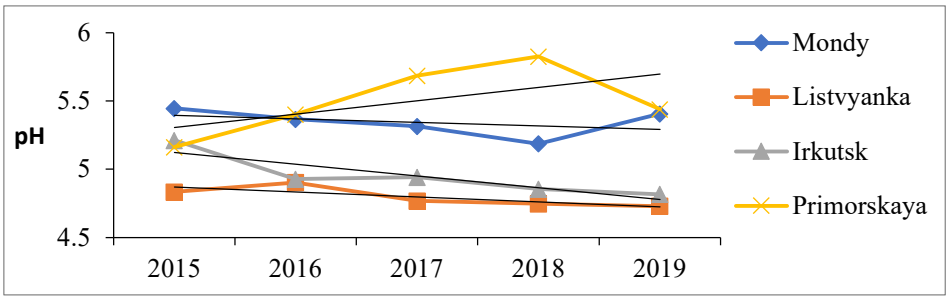

Fig. 3.4. The average annual variations (from 2015 to 2019) of pH values in precipitation at the EANET monitoring stations.

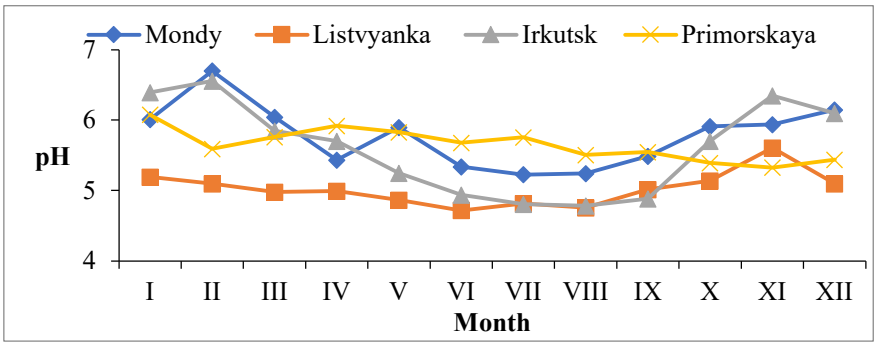

Figure. 3.5. Seasonal dynamics of the precipitation-weighted average pH (2015 to 2019).

From 2015 to 2019, at stations Listvyanka and Irkutsk, the frequency of acid deposition gradually increased. Thus, between 2015 and 2019, 52% of the precipitation that fell near station Listvyanka had a pH below 5.0, and its highest frequency (pH below 5.0) was recorded in 2019 (Fig. 3.6). At station Irkutsk, acid deposition fell two or three times rarer than at station Listvyanka, also with the maximum frequency in 2019. At stations Mondy and Primorskaya, the amount of acid deposition with pH below 5.0 averaged only from 8 to 9%.

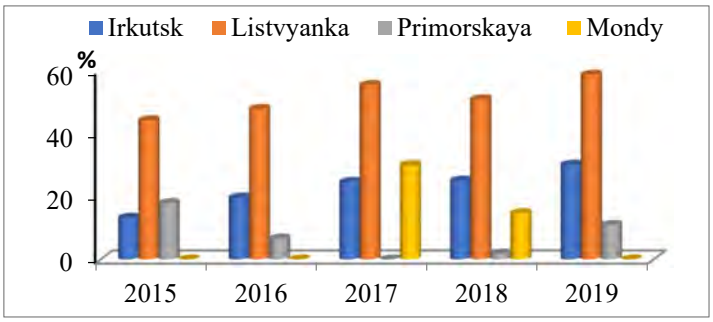

Figure 3.6. Annual variations (from 2015 to 2019) in the percentage of precipitation with pH < 5.0 at the EANET monitoring stations in Russia.

3.2. Deposition

Table 3.2 presents annual values of wet deposition of ions at the EANET monitoring stations from 2015 to 2019. The largest number of ions deposit at station Primorskaya, which is due to a much greater (by a factor of 2 to 4) amount of precipitation here. In comparison with the urban Irkutsk site,

the influx of various salts entering the underlying surface in this area is on average 3 times higher, and in comparison with the remote Mondy site – 20 times higher.

At all stations, mineral nitrogen fluxes exceeded sulphur fluxes (Fig. 3.7), and this excess ranged from 2.8 (Irkutsk) to 5.4 (Mondy) times. In the Primorsky Kray, there were two times more nitrogen and sulphur depositions than in Irkutsk. At stations Irkutsk and Primorskaya, sulphur and nitrogen depositions tended to decrease from 2015 to 2019; at station Mondy, there was no significant trend. In Listvyanka, nitrogen fluxes decreased by 27% (owing to ammonium fluxes), and sulphur fluxes increased by 17%. The fluxes of the H^+ ions in Irkutsk and Listvyanka were almost the same, which had not been previously observed. Moreover, from 2015 to 2019, there was a 3.3-fold increase in these fluxes at the urban site and a 1.6-fold increase at the rural site. In some years (2016 and 2018), the H^+ fluxes were higher in Irkutsk than in Listvyanka (Table 3.2). At station Primorskaya, there was more than a two-fold decrease in the H^+ deposition for five years.

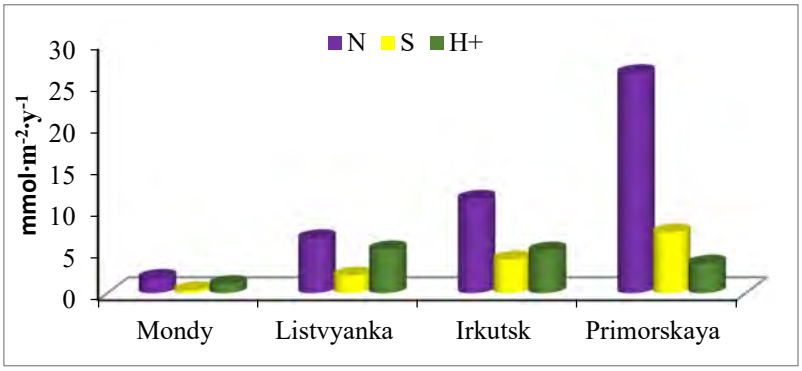

Figure 3.7. Average long-term (from 2015 to 2019) fluxes of ions of acid components (nitrogen, sulfur and hydrogen) at the EANET monitoring stations, mmol·m^{-2}·y^{-1}.

Table 3.2 Wet deposition of ions at the EANET monitoring stations, mg·m^{-2}·y^{-1}

Year	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	H^+	$\sum_i$
Irkutsk											
2015	311	1226	380	249	90	56	375	41	391	2.2	3121
2016	420	1095	400	168	82	59	331	47	276	5.0	2883
2017	562	1246	447	180	93	55	462	58	267	4.9	3375
2018	730	1378	372	162	93	57	517	62	194	5.1	3570
2019	368	1137	420	165	61	64	281	41	383	7.2	2927
Listvyanka											
2015	19	679	322	65	23	28	134	17	222	5.0	375
2016	20	366	294	35	20	21	100	15	82	3.9	326
2017	58	792	434	50	27	52	184	29	129	5,8	505
2018	15	459	248	23	15	18	111	16	56	4.0	647
2019	50	800	426	64	30	51	138	24	145	8.0	330
Mondy											
2015	121	83	44	18	5	18	45	7	33	0.5	375
2016	77	67	79	13	7	9	48	5	20	1.0	326
2017	52	126	134	37	12	16	75	9	43	1.1	505
2018	165	152	119	31	18	18	78	9	55	2.4	647
2019	60	82	87	13	8	7	37	4	31	1.0	330
Primorskaya											
2015	471	2164	1657	964	682	326	572	146	519	7.8	7509
2016	444	2008	1098	1019	541	661	474	118	372	3.4	6738
2017	540	1594	1086	652	324	214	452	156	470	1.2	5489
2018	1037	2628	1490	630	506	325	602	222	639	1.4	8080
2019	549	1230	1064	1002	386	272	402	180	376	3.5	5465

3.3 Spatial distribution of wet deposition

Based on 20 years of continuous observations of the composition of gaseous pollutants and aerosol at four EANET monitoring stations operating in Russia, seasonal and interannual dynamics, as well as periods with high and low concentrations of major ions in aerosol and gaseous pollutants, were analyzed. In East Siberia (Baikal region), the concentrations of the total amounts of ions decreased at three monitoring stations from 2000 to 2019, and in the Primorsky Kray − from 2002 to 2019. The ratios of ions in aerosol changed due to climatic conditions and a decrease in atmospheric emissions of pollutants, which is caused by climate warming and the growth in the number and area of wildfires both in Siberia and in the Far East.

The results of monitoring the chemical composition of precipitation revealed that the most mineralized precipitation fell at the urban Irkutsk site (16.7 mg/L) and the least mineralized one – at the remote Mondy site (3.2 mg/L). At these sites, the concentrations of major ions and mineralization in precipitation tended to decrease from 2015 to 2019, and their interannual dynamics was directly associated with the amount of precipitation. Ca^{2+} and SO_4^{2-} were the main components in the ionic

composition of precipitation at the stations in East Siberia (Baikal region), and SO_4^{2-} and NH_4^+ – at station Primorskaya (Primorsky Kray). At station Listvyanka, the concentrations of major ions in precipitation increased. At station Primorskaya, only an increase in the Cl^- concentration was observed in the interannual dynamics; the concentrations of other ions decreased by 2019.

In the Baikal region, the trend towards acidification of precipitation continued, with the minimum pH values in 2019. On the contrary, in the Primorsky Kray, the frequency of acid deposition decreased by 2019. From 2015 to 2019, the frequency of acid precipitation increased at stations Listvyanka and Irkutsk and decreased at station Primorskaya. As between 2010 and 2014, the most acid deposition with pH of 4.8 was at station Listvyanka; at station Primorskaya, pH was 5.5. The rains with pH values below 5.0 were 52% of the annual amount of precipitation at station Listvyanka, 23% at station Irkutsk and 8% at station Primorskaya. In the seasonal aspect the acid deposition in the Baikal region was observed the most frequently from June to August, and in the Primorsky Kray in November.

The highest influx of all chemical components (ions) to the underlying surface with precipitation, except for hydrogen ions, was determined at station Primorskaya where the highest amount of precipitation was also recorded. As previously, the lowest number of salts deposited at station Mondy where the low ionic concentration and a small amount of precipitation were recorded. At all stations, except for Listvyanka, wet deposition fluxes of substances decreased by 2019. Fluxes of hydrogen ions on average remained maximum at station Listvyanka where the acidification of precipitation took place. One of the causes of the growth of acid components in precipitation at station Listvyanka is associated with large traffic in this tourist zone of the southern basin of Lake Baikal as well as with the growth of wildfires in the region. Also, of concern is the trend towards an increase in acid deposition by 2019 at station Irkutsk, which is associated with the same situation as at station Listvyanka. As a contrary there was a trend towards decreasing the amount of acid deposition and the fluxes of hydrogen ions onto the underlying surface in the Primorsky Kray over five years of observations.

4. Inland aquatic environment

4.1. Pereemnaya River

The Pereemnaya River, a tributary in the southern basin of Lake Baikal, was chosen as a model object for studying the influence of acidified precipitation on the chemistry of surface waters. The river starts near Sokhor Mounts of the northern macro slope of the Khamar-Daban Ridge at an altitude of 2,316 m. Its length is 42 km, and it drainages the watershed basin of about 462 km^2 with average height of 1,260 m a.s.l. The Archean rocks represented mainly by gneisses, schists and pegmatites are developed in the basin. The most part of the basin is in the taiga soil zone, with the soils characterised mainly by acidic pH. The river is fed by precipitation. In the area of the Khamar-Daban Ridge and the Pereemnaya River basin, the annual amount of precipitation is the highest in the Baikal region: up to 1,060-1,720 mm. The thickness of snow may reach 2 m.

The observations of the Pereemnaya River mainly aim to estimate the impact of acidic components coming from the atmosphere on the chemical composition of the river waters near the southeast coast of Lake Baikal located 38 km from the atmospheric monitoring station, Listvyanka.

According to the previous studies, the Pereemnaya River is the most representative for reflecting the changes in the chemical composition of river waters caused by the influx of pollutants through the atmospheric channel (Netsvetaeva et al., 2004).

In the study area, the Baikalsk Pulp and Paper Mill (BPPM) situated 70 km from the river was a substantial source of technogenic emissions from 1966 to 2013. After the terminating operation of BPPM in 2013, the main sources of polluting components are the thermal power plant of the Baikalsk town, the Trans-Siberian Railway and the highway running along the lakeshore, local sources of the Tankhoy settlement as well as industrial emissions in the southern part of the Baikal region penetrating this area with air masses along the valley of the Angara River (Tomberg et al., 2016).

Figure 4.1 shows sites for monitoring the atmosphere and river waters. Numbers in Fig. 4.1 show annual SO_2 emissions (thou tons per year) in the largest cities and towns of the region.

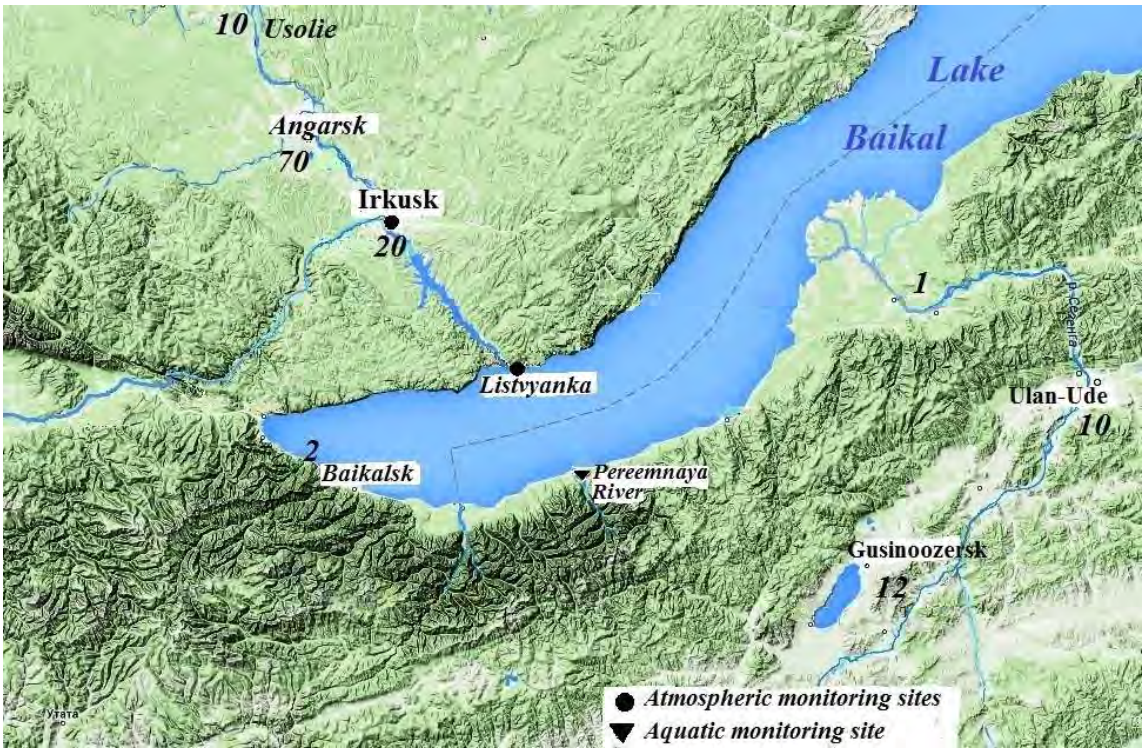

Figure 4.1. The layout of atmospheric monitoring stations Irkutsk (urban site) and Listvyanka (rural site) as well as Pereemnaya River (aquatic monitoring site).

From 2015 to 2019, like in previous years, water was sampled from the surface under different water conditions (winter low-water period, flood period, summer and autumn low-water period) ~ 1 km from the river estuary. At the sampling site, pH and electrical conductance were measured; dissolved oxygen was recorded, and other components were analyzed in the laboratory,

The total amount of ions (Σ_i) in the water of the Pereemnaya River during the observation period (from 2015 to 2019) varied depending on the season from 19.6 to 33.6 mg/L. The lowest ionic concentrations in the river were observed during high water when poorly mineralized snow water entered the riverbed. After the spring minimum, the concentrations of major ions, as well as their total concentrations in the river, increased gradually, reaching the maximum in winter (Fig.4.2).

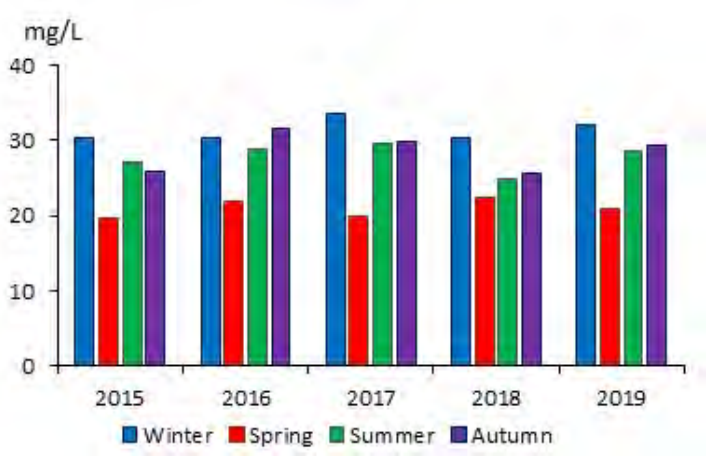

Figure 4.2. Seasonal fluctuations in the total amount of ions in the water of the Pereemnaya River from 2015 to 2019.

In the long-term aspect, the mineralization of the water in the Pereemnaya River increased gradually. In 2005, the maximum total amount of ions was 25.3 mg/L; from 2010 to 2014, it was recorded at the level of 31-32 mg/L, and from 2015 to 2019 – 30.3-33.6 mg/L. The increase in the ionic concentration may be associated with reduced water content in this period as well as with a likely intensification of the weathering of rocks in the river basin under the influence of a large amount of precipitation with high acidity (the average pH of snow water in this area ranges from 4.4 to 4.6). In comparison with the 1996 data, the modern Σ_i values of the river water increased by 20 to 32% depending on the water content conditions. The seasonal dynamics of the concentrations of major ions and their total amount remain unchanged and are mainly determined by the change in the water content. Between 2015 and 2019, the concentrations of sulfate varied from 6.9 to 13.6 mg/L and were lower on average than that between 2010 and 2014 (from 6.4 to 15.9 mg/*L*).

During the pre-industrial period in the southern part of the Baikal region (from 1950 to 1955), the HCO_3^- and Ca^{2+} ions were the main components of the chemical composition of the water in the Pereemnaya River (Votintsev et al., 1965). In the modern period when acidic components from the atmosphere enter the watershed basin of the river with precipitation and during the dry deposition, there is a change in the relative composition of major ions in the river water as well as an increase in the concentrations of SO_4^{2-} and NO_3^-. In the long-term aspect, in the Pereemnaya River, the HCO_3^- concentrations tended to decrease; the Ca^{2+} concentration slightly increased, and the SO_4^{2-} increased by 40-42 % (Fig. 4.3). In subsequent years, the relative composition of major ions in the river water mainly corresponded to sulfate class and calcium group.

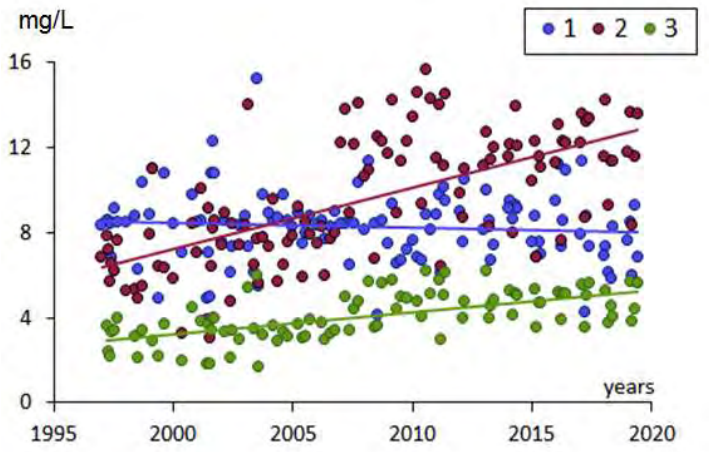

Figure 4.3. Tendencies of the changes in the concentrations of major ions in the water of the Pereemnaya River: 1 – bicarbonates, 2 – sulfates and 3 – calcium. Straight lines are the approximation of the corresponding linear trends.

From 2015 to 2019, the seasonal dynamics of the concentrations slightly differed from those in previous years. There was an increase of the average annual concentrations of NO_3^- in the river water due to input of higher snowmelt (Fig. 4.4) and spring floods in the river basin (Sorokovikova et al., 2020). The seasonal dynamics of the concentrations of nitrate nitrogen in summer and autumn remained stable. In summer, during the intensive development of plankton, the NO_3^- concentrations were minimal; in autumn, they gradually increased in the river water (Fig. 4.4).

The concentration of NH_4^+ in the river water is mainly related to the dynamics of the water runoff and the influx from the watershed area during spring and summer floods. The NH_4^+ concentrations in the winter low-water period did not exceed 0.002 mg NH_4^+/L, and during the summer low-water period, they mainly varied within 0.008 NH_4^+/L, increasing during high water to 0.014-0.028 mg NH_4^+/L.

The NO_2^- concentrations were recorded in the water of the Pereemnaya River at a low level, from 0.001 to 0.003 mg NO_2^-/L. There were no changes in the concentrations of this component.

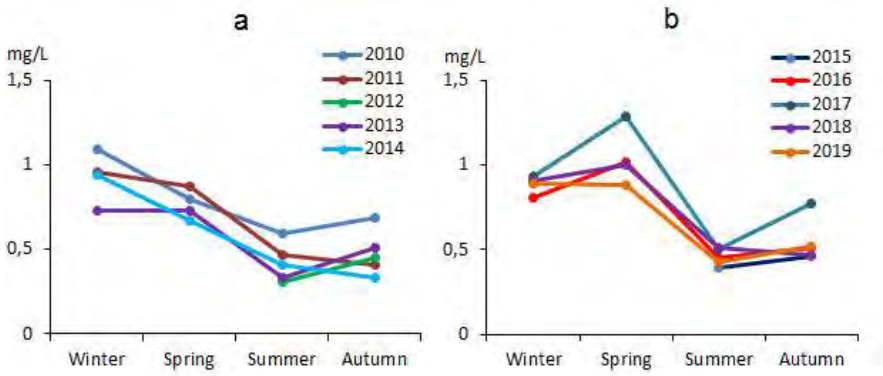

Figure 4.4. Seasonal fluctuations of nitrate nitrogen (mg/L) in the water of the Pereemnaya River from 2010 to 2019.

The dynamics of mineral and total phosphorus in the Pereemnaya River is shown in Figure 4.5. The concentrations of them in the river did not exceed 0.005 and 0.010 mg P/*L*, respectively. There was no definite pattern in the seasonal and interannual dynamics of both mineral and total phosphorus. The maximum concentrations were observed in the winter of 2015; the minimum concentrations of mineral phosphorus were observed in the springs of 2015 and 2018, and those of total phosphorus – in the summer of 2015.

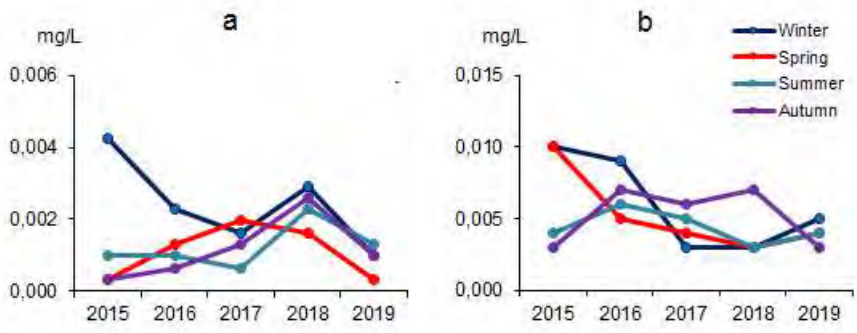

Figure 4.5. Seasonal fluctuations of mineral (a) and total (b) phosphorus in the water of the Pereemnaya River from 2015 to 2019.

To characterize organic matter (OM) in water, permanganate oxygen demand (POD) was determined. From 2015 to 2019, POD varied from 0.31 to 1.90 mg O/*L* and was close to that between 2010 and 2014 (0.38 -1.65 mg O/*L*). The concentration of organic carbon varied in seasonal aspect from 0.30 to 2.20 mg C/*L*. The minimum concentrations of organic carbon in water were observed in winter, and the maximum ones – during summer and autumn floods, resulting from the influx of organic compounds from the watershed (Fig.4.6).

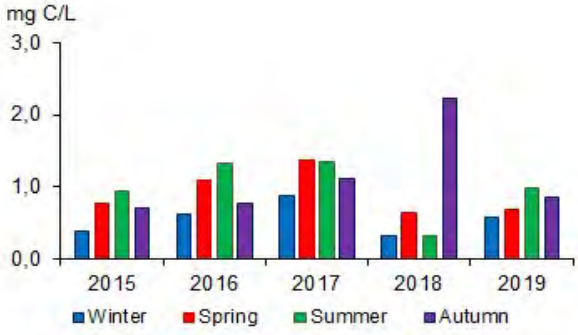

Figure 4.6. Seasonal fluctuations of organic matter in the water of the Pereemnaya River from 2015 to 2019.

In the observation period, the pH value of the water in the Pereemnaya River varied from 6.39 to 6.93 (Fig. 4.7) and was lower than that between 2010 and 2014 (6.56 to 7.21). The higher pH values were recorded in summer; the minimum ones – in spring during snowmelt. As a rule, the decrease in pH during summer and autumn is due to high water and the influx of acid deposition to the riverbed. In the long-term aspect, the pH value of snow waters in the basin of the Pereemnaya River gradually decreased: from 2015 to 2019, it averaged 4.64. The ratios of equivalent concentrations of cations ($K = (Ca^{2+} + Mg^{2+} + NH_4^{+} + Na^{+})$) and anions ($A = (SO_4^{2-} + NO_3^{-})$) in the river water over the observation

period decreased from 0.7 to 0.6 compared to the previous observations, indicating their further acidification (Sorokovikova et al., 2020).

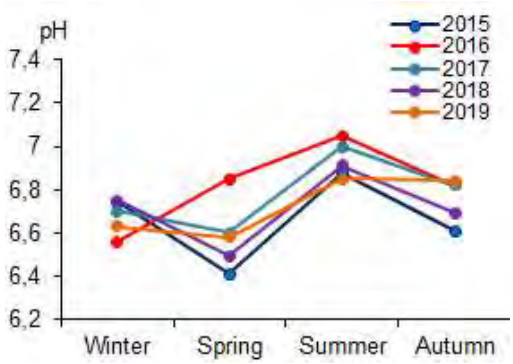

Figure 4.7. The pH fluctuations in the water of the Pereemnaya River from 2015 to 2019.

The water in the Pereemnaya River is well aerated, and the concentrations of dissolved oxygen varied insignificantly, from 9.1 to 12.5 mg/L. The maximum concentrations of dissolved oxygen in the Pereemnaya River were observed in late autumn owing to an increase in its water solubility with a decrease in temperature. Moreover, elevated concentrations were recorded in winter, resulting from the formation of gullies in the ice, which contributes to the water aeration.

4.2. The Komarovka River

The Komarovka River, a mountain river, was chosen as a model object for studying the influence of atmospheric precipitation on the chemistry of surface waters in the Primorsky region. The river originates in spurs of the Sikhote-Alin Ridge at an altitude of 380 m above sea level. Being the left tributary of the Razdolnaya River, the Komarovka River belongs to the Japanese Sea basin. Its length is about 66 km. Mean annual water discharge varies from 0.66 m^3/s to 3.79 m^3/s, averaging 1.55 m^3/s. The observation site is located at the hydrological post “Tsentralny” within the area of station Primorskaya, 34 km far from the Ussuriisk city and 44 km from the river mouth.

There are no stationary pollution sources of the river stream at the observation site and upward. The river is likely affected by rain flow from the watershed and by snow waters. Hydrochemical observations have been carried out on the river since 2005. From 2015 to 2019, like in previous years, the studies were carried out 5 times per year: in February, April, June, September, and November, thus, recording changes in the chemical composition of the river waters during different hydrological periods and different years.

During the observation period, the water temperature in the river varied from 0.1 °C to 12.0 °C; the maximum temperatures were in June. Water in the Komarovka River is low-mineralized and soft. From 2015 to 2019, like from 2010 to 2014, mineralization of water varied throughout the year within a narrow range from 44.1 to 67.7 mg/L, with an increase in the total amount of ions in autumn and winter (Fig. 4.8).

Figure 4.8. Seasonal fluctuations of the total amount of ions in the water of the Komarovka River from 2015 to 2019.

Figure 4.9 presents the interannual and seasonal dynamics of the SO_4^{2-} concentrations in the river water. There was no definite pattern in the seasonal dynamics of the concentrations. In 2015 and 2017, elevated concentrations of SO_4^{2-} were observed in winter with low water content. In 2016 and 2018, the highest concentrations were recorded in June, and in 2019 – in November, which is likely due to the inflow from the watershed resulted from high water.

Figure 4.9. Annual fluctuations of SO_4^{2-} (mg/L) in surface water of the Komarovka River in 2015-2019.

From 2015 to 2019, the concentrations of Cl^- in the river water varied from 1.7 to 5.7 mg/L, with the maximum values in winter and the minimum ones in spring and autumn. The concentrations of Na^+

fluctuated from 2.5 to 5.7 mg/L, K^+– from 0.3 to 1.4 mg/L, Ca^{2+}– from 5.8 to 11.5 mg/L, and Mg^{2+}– from 1.2 to 3.3 mg/L. The analysis of the obtained results revealed that the concentrations of major ions in the water of the Komarovka River varied throughout the year and in the interannual aspect within a narrow range. There were no definite seasonal and interannual patterns in the dynamics of their concentrations.

Figure 4.10 shows the data on the dynamics of NO_3^- and NH_4^+ in the water of the Komarovka River from 2015 to 2019.

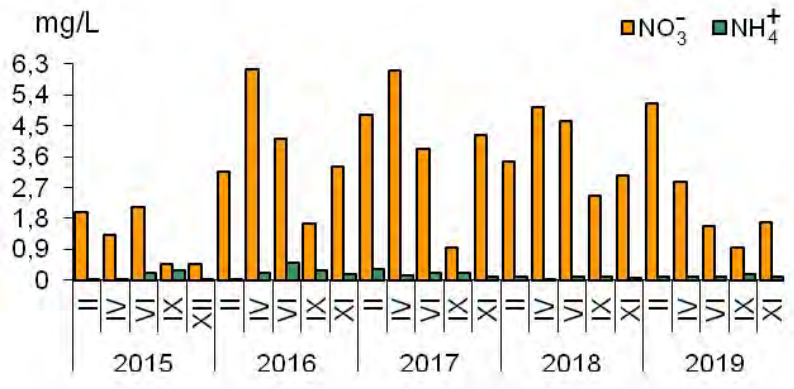

Figure 4.10. Fluctuations of the NO_3^- and NH_4^+ concentrations in the water of the Komarovka River from 2015 to 2019.

The concentration of NO_3^- in the water of the Komarovka River varied from 0.45 to 4.82 mg NO_3^-/L; a decrease was observed in summer and autumn, which was likely due to the development of plankton. The exception was June 2016 when the concentration of this component in water reached 6.15 mg NO_3^-/ L, which was likely due to the influx of nitrogen from the watershed during the high water. The NH_4^+ concentrations mainly varied from 0.005 to 0.280 mg NH_4^+/L, and only in June 2016, it increased to 0.485 mg NH_4^+/L. The increase in the NH_4^+ concentration, like NO_3^-, was caused by the inflow from the watershed. The concentration of NO_2^- in the water of the Komarovka River varied from 0.005 to 0.048 mg NO_2^-/L. There was no definite pattern in the seasonal and interannual dynamics of the NO_2^- concentration.

Between 2015 and 2019, the concentration of mineral phosphorus in the river water varied from 0.001 and 0.013 mg P/L. There was no definite dynamics in the concentrations of mineral phosphorus.

The concentration of silica varied throughout the year from 3.8 to 7.5 mg Si/L; however, there was also no definite seasonal dynamics.

The pH value of the water in the Komarovka River varied from 6.51 to 7.25 (Fig. 4.11), with the minimum values in spring and summer. The pH value above 7.0 was recorded in late autumn and winter. The river water is rich in dissolved oxygen ranging from 9.2 to 14.1 mg/L. Its low values were mainly observed in June, and the elevated ones – from November to February.

Figure 4.11. Fluctuations of the pH value in the water of the Komarovka River from 2015 to 2019.

POD varied from 1.6 to 7.0 mg O/L (Fig. 4.12). It had the minimum values in winter (from 1.6 to 2.1 mg O/L). Its increase was recorded during high water or summer and autumn floods, which is due to the influx of OM from the watershed. During these periods, POD varied from 4.8 to 7.0 mg O/L. The water in the Komarovka River is saturated with dissolved oxygen, the concentrations of which did not decrease below 9.2 mg/L.

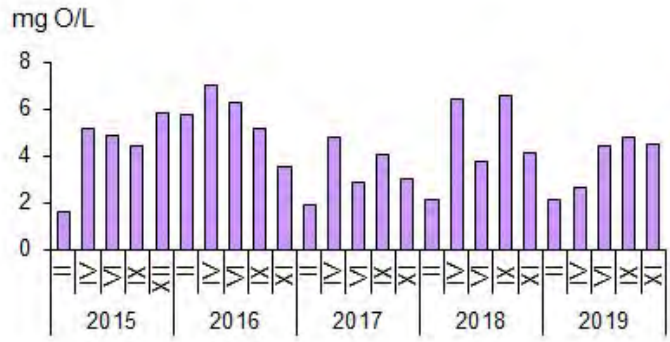

Figure 4.12. Fluctuations of POD in the water of the Komarovka River from 2015 to 2019.

Long-term monitoring observations that were carried out on the rivers of the Asian part of Russia under the EANET program have revealed that the Pereemnaya River has low concentrations of major ions and low mineralization of water. In terms of the relative concentrations of major ions, the water in the river in the modern period (from 2014 to 2019) corresponds to the sulfate class and the calcium group, which was previously shown only sporadically. There are elevated concentrations of sulfates and nitrate nitrogen as well as low pH values. With the main feeding of the river by precipitation, there is a low buffer capacity of the river water, which predetermines its non-resistance to acidification.

Studies of the water in the Komarovka River revealed that seasonal and interannual dynamics of the concentrations of major ions and mineralization varied from 2015 to 2019 within the narrow range. The concentration and the relative composition of major ions in the water remain rather stable. During high water, elevated concentrations of mineral forms of nitrogen were recorded in the river water. The pH value of the water in the Komarovka River is close to neutral with the minimum in

spring and summer and the maximum in late autumn and winter.

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National Assessment on Acid Deposition in Thailand

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1. Basic Information on National Monitoring Activities

1.1. Outline of the activities on acid deposition and national monitoring plan

Acid deposition monitoring network consists of several activities, including monitoring of both wet and dry depositions and monitoring of ecological impacts on soil, vegetation and inland aquatic environments. Air Quality and Noise Management Division, Pollution Control Department, has been appointed by the Royal Thai Government as the National Focal Point and the National Center for the Acid Deposition Monitoring Network in East Asia (EANET). Thailand participated in the preparatory phase of (EANET) during 1998-2000. Since then, EANET activities have been implemented on a regular basis together with the others East Asian countries.

Thailand's acid deposition monitoring network classified into EANET sites and national sites. There are 6 EANET monitoring sites: two urban (Bangkok), three rural (Pathumthani, Chiang Mai and Nakhon Ratchasima) and one remote site (Kanchanaburi). In addition to EANET sites, Thailand attempts to set up the national sites to examine the status of the other regions of the country and some specific areas such as the industrial complexes. These sites were not continuously operated due to limited resources and budget. At present, there are 3 national sites that attain the continuous operation, which include Songkhla, Chonburi and Rayong. All 3 sites are classified as urban sites. Songkhla is located in the South of Thailand. Chonburi and Rayong are the sites located in the Eastern part within the vicinity of the large industrial complexes, including power plants, petrochemical plants, oil refinery, gas separation plants, steel industries and automobile manufacturing plants. The monitoring sites are as shown in Figure 1.

The monitoring activities have started since 2000. Generally, all stations monitor both wet and dry depositions. The wet deposition daily sampling is collected by the automatic wet-only sampler. The dry deposition is carried out by either automatic ambient air monitoring stations and/or the four-stage filter pack collected every ten days in monthly basis. The status of acid deposition in Thailand presented in this report is based on the 6 EANET sites and 3 national sites.

1.2 Monitoring program from 2000 to 2019

National Monitoring Plan from 2000 to 2019 in Thailand were developed by the Air Quality and Noise Management Division, Pollution Control Department, which included the monitoring sites, the activities and monitoring parameters, the responsible agencies as well as the monitoring schedule. The monitoring program included four major environmental aspects; Wet and Dry

Deposition, Soil and Vegetation and Inland Aquatic Environment are carried out in line with EANET monitoring guidelines.

1.3 Monitoring stations

There are 6 designated EANET monitoring sites and 3 national sites as summarized in Table 1.

(1) Khanchanaburi (EANET site), located at Vajiralongkorn Dam, Khanchanaburi province (Remote Site): monitoring for wet deposition; dry deposition is monitored by automatic analyzer and filter pack, Inland aquatic environment, soil and vegetation are also included in this site.

(2) Bangkok (EANET site), located in the area of Pollution Control Department (PCD) and The Government Public Relations Department (PRD), Bangkok (Urban Site): PRD site monitoring is for dry deposition by automatic analyzer and filter pack; PCD site monitoring is for wet deposition. Both sites located in the same area.

(3) Samutprakarn (EANET site), located at Thai Meteorological Department (TMD), Bangkok (Urban Site): monitoring for wet deposition and dry deposition by automatic analyzer.

(4) Pathumthani (EANET site), located at the Environmental Research and Training Center (ERTC), Pathumthani Province (Rural Site): monitoring for wet deposition.

(5) Chiang Mai (EANET site), located at Chiang Mai University (CMU), Mae-Hia Campus, Chiang Mai Province (Rural Site): monitoring for wet deposition and dry deposition by filter pack.

(6) Nakhon Ratchasima (EANET site), located at Sakaerat Silvicultural Research Station (SKR), Nakhon Ratchasima Province (Rural Site): monitoring for wet deposition and dry deposition by filter pack.

(7) Songkhla (National site), located at Kohong Meteorological Station, Songkhla Province (Urban Site): monitoring for wet deposition and dry deposition by filter pack.

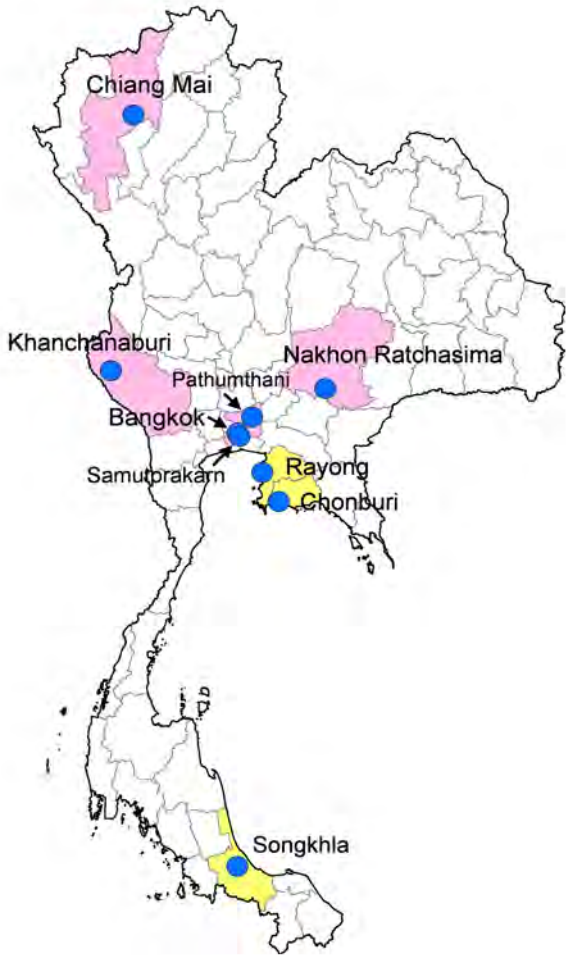


Figure 1. Acid Deposition Monitoring Sites in Thailand.

(8) Chonburi (National site), located at Kasetsart University Si Racha Campus, Chonburi Province

(Urban Site): monitoring for wet deposition and dry deposition by automatic analyzer and filter pack.

(9) Rayong (National site), located at Rayong-Health Promotion Hospital Maptaput, Rayong Province (Urban Site): monitoring for wet deposition and dry deposition by automatic analyzer.

Table 1 Locations of EANET Monitoring Sites in Thailand

City	Site	Classification	Latitude	Longitude	Altitude (m)
Bangkok	Bangkok	Urban	13°47′04″N	100°32′22″E	5
	Samutprakarn	Urban	13°39′58″N	100°36′21″E	4
Pathumthani	Pathumthani	Rural	14°02′46″N	100°42′43″E	6
Khanchanaburi	Khanchanaburi (Vachiralongkorn Dam)	Remote	14°47′05″N	98°36′05″E	130
Chiang Mai	Chiang Mai (Mae Hia)	Rural	18°45′54″N	98°55′42″E	349
Nakhon Ratchasima	Nakhon Ratchasima	Rural	14°28′04″N	101°54′05″E	409
Songkhla	Songkhla	Urban	7°01′23″N	100°29′56″E	12
Chonburi	Chonburi	Urban	13°07′15″N	100°55′10″E	36
Rayong	Rayong	Urban	12°42′31″N	101°09′58″E	23

1.4 Sampling and Measurements

The measurement parameters and monitoring interval are summarized as shown in Table 2.

(1) Wet Deposition Monitoring

Wet deposition is monitored by "Wet-Only-Sampler" resulted in concentration. Rain gauge is used for precipitation measurement. Twenty-four hours composite samples are collected in polyethylene collecting bottles. Rain samples are weighted and then analyzed for chemical composition (EC, pH and ionic species). If the samples cannot be analyzed within one day or is needed to be transferred from the sampling location to the laboratory, the samples are required to refrigerate at 4 ◦c or kept in a box with freezer packs and sent to the laboratory on daily basis.

(2) Dry Deposition Monitoring

Atmospheric gases concentrations, i.e., SO_2, NO_x and O_3, are measured on-site by automatic analyzers at Bangkok, Samutprakarn, Chonburi, Rayong and Khanchanaburi. At Khanchanaburi site, SO_2, NO_x and O_3 are monitored for 2 weeks, three times per year in March, July and November. At Bangkok and Samutprakarn sites, SO_2, NO_x and O_3 are monitored continuously all year round.

Atmospheric gases and aerosols concentrations are measured by filter pack method at Chiang Mai, Bangkok, Nakhon Ratchasima, Pathumthani, Chonburi, Songkhla and Khanchanaburi. Duration of sampling in all sites except Khanchanaburi is 10 days/sample continuously. For Khanchanaburi,

the sampling frequency is three times per year (14 days/sample) at the same monitoring period using an automatic analyzer. That samples are analyzed for SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Mg^{2+} and Ca^{2+} in particulate (aerosol) and analyzed for SO_2, HNO_3, NH_3 and HCl in gas phase.

(3) Inland Aquatic Environments Monitoring

Inland aquatic environments are monitored at Khanchanaburi. Samples are collected from two locations in Vajiralongkorn Reservoir, namely Ban Pong Chang (BPC) and Ban Pang Pueng (BPP) stations. The sampling frequency for inland aquatic environment monitoring is every 3 months, 4 times per year in March, June, September and December.

Table 2 Measurement parameters and monitoring interval

Items	Measurement parameters	Monitoring interval
Wet deposition	pH, EC, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^-, precipitation amount, CH_3COO^-, $HCOO^-$, PO_4^{3-}	daily
Dry deposition - Automatic analyzer	SO_2, NO_2, NO, O_3, Particulate Matter (PM-10)	- hourly
- Filter pack	HNO_3 , SO_2, NH_3, HCl, Aerosol	- 10 days
Soil	pH (H_2O), pH (KCl), exchangeable (Na^+, K^+, Ca^{2+}, Mg^{2+}), Exchangeable acidity, ECEC, Moisture content	every 3-5 years
Vegetation	observation of tree decline, description of trees	every 3 years
Inland aquatic environment	water temperature, pH, EC, alkalinity, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^-, transparency	4 times/year

2. State of Acid Deposition in Thailand

2.1 State of wet deposition

The status of wet deposition in Thailand presented in this report was analyzed based on the EANET data of twenty-year period from 2000 to 2019. In addition to 6 EANET sites in Thailand, Thailand has been attempted to set up the other national sites. Three national sites have also been used to examine the status of wet deposition in Thailand including Songkhla, Chonburi and Rayong.

The acidity or pH of rainwater depends on the concentration of cationic and anionic species. Acidic pH reveals the presence of strong acids, such as SO_4^{2-} and NO_3^-, while neutral or alkaline pH values indicate neutralization of acids by NH_4^+ and soil dust. The naturally existing CO_2, NO_x and SO_2 will dissolve into the clouds and rain droplets then result in pH values of the rain in the clean atmosphere to be between 5.0 and 5.6

Figure 2. shows the annual mean pH of all monitoring sites in Thailand from 2000-2019. It was found that the tendency of the annual mean pH was shown slightly increasing trend for most of the sites except for Rayong (urban), Chonburi (urban) and Chiang Mai (rural), which have not appeared considerably changed. Annual mean pH was ranged from 4.20-7.03 which the lowest pH was observed at Chonburi in 2011 and the highest pH was at Bangkok in 2014. Twenty-years weighted average pH were ranged from 4.56-5.64 which the lowest pH was observed at Chonburi and the highest pH was at Khanchanaburi (remote) as shown in Figure 3.

Figure 4. shows the percentage of sample which pH lower than 5.6 during 2000-2019. It was found that percentage of sample which pH lower than 5.6 were ranged from 18.3-85.0 which the lowest value was observed at Chiang Mai and the highest value was at Rayong. It was also observed that the monitoring sites located in the vicinity of the industrial areas including Chonburi and Rayong were shown pH lower than 5.6 at most of the samples. In contrary, the other six monitoring sites located in urban, rural and remote areas, were shown that less than 50 percent of samples having pH lower than 5.6.

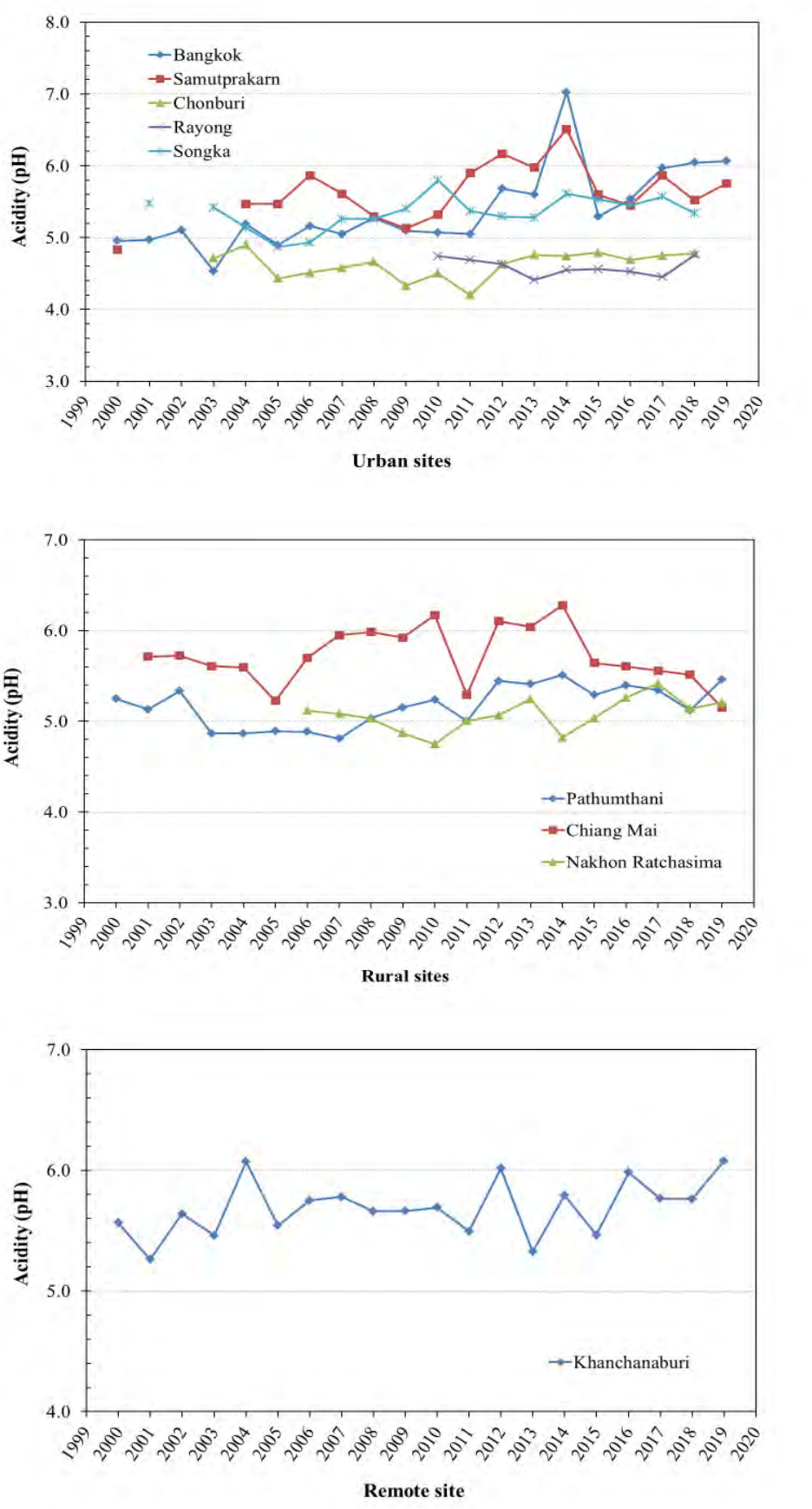


Figure 2. Annual mean pH for the monitoring sites in Thailand during 2000-2019.

Note: Rain sample of Bangkok (PCD) for all year round in 2014 carried out on daily basis by bulk method

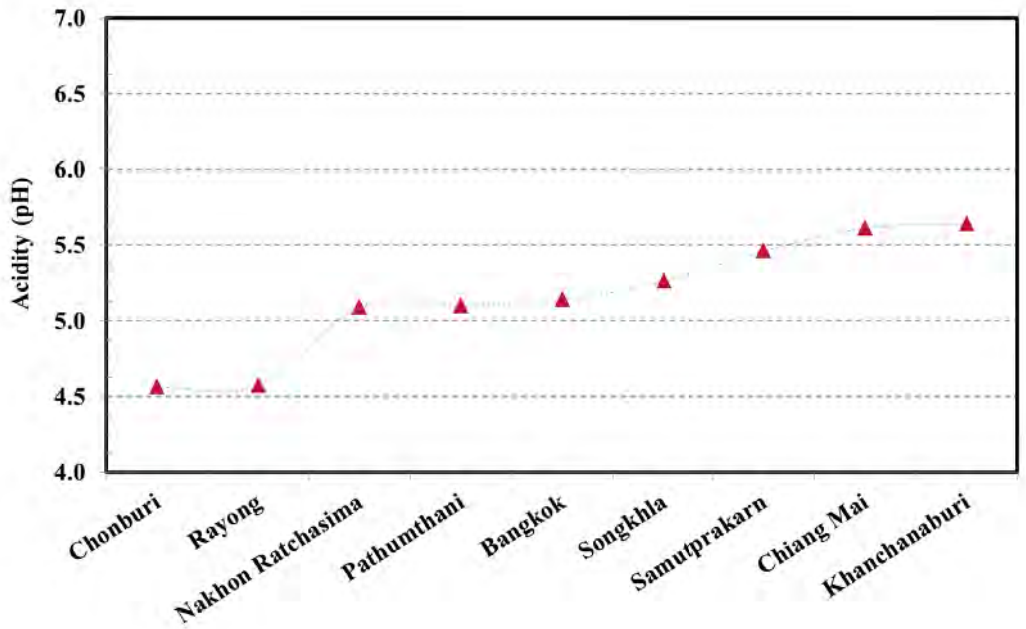


Figure 3. Twenty-year weighted average pH (2000-2019).

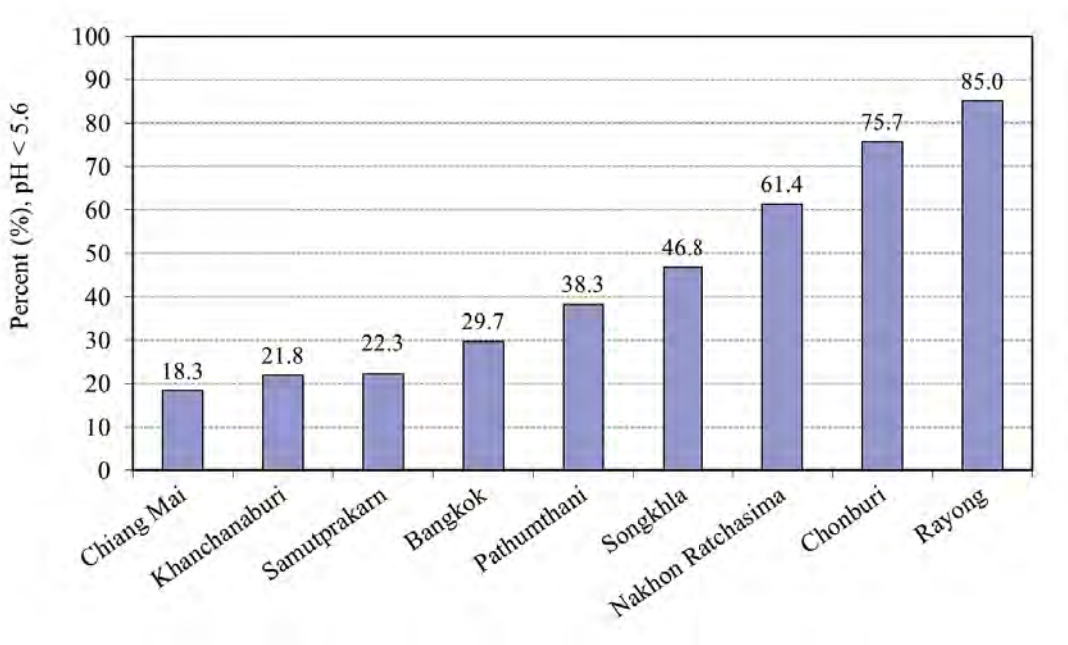


Figure 4. Percentage of Sample which pH lower than 5.6 during 2000-2019.

Frequency distribution of pH during 2000-2019 is shown in Figure 5. In this study, pH range of urban areas (industrial areas) were mostly found at range lower than 4.5 to 5.0, i.e., Chonburi at pH lower than 4.5 to 5.0 with n = 1,395 and Rayong at pH range of 4.5-5.0 with n = 561. Urban area (city area), pH level was found normally at pH range of 5.5-6.5, i.e., Bangkok (PCD) at pH range of 6.0-6.5 with n = 1,246, Samutprakarn (TMD) at pH range of 6.0-6.5 with n = 1,211 and

Songkhla at pH range of 5.5-6.0 with n = 1,987. For rural areas, pH level was found normally at pH range of 5.5-6.5, i.e., Nakhon Ratchasima at pH range of 5.5-6.0 with n = 1,713, Pathumthani at pH range of 6.0-6.5 with n = 1,705 and Chiang Mai at pH range of 6.0-6.5 with n = 1,784. For remote area at Khanchanaburi, the pH level was found normally at pH range of 5.5-6.0 with n = 1,451.

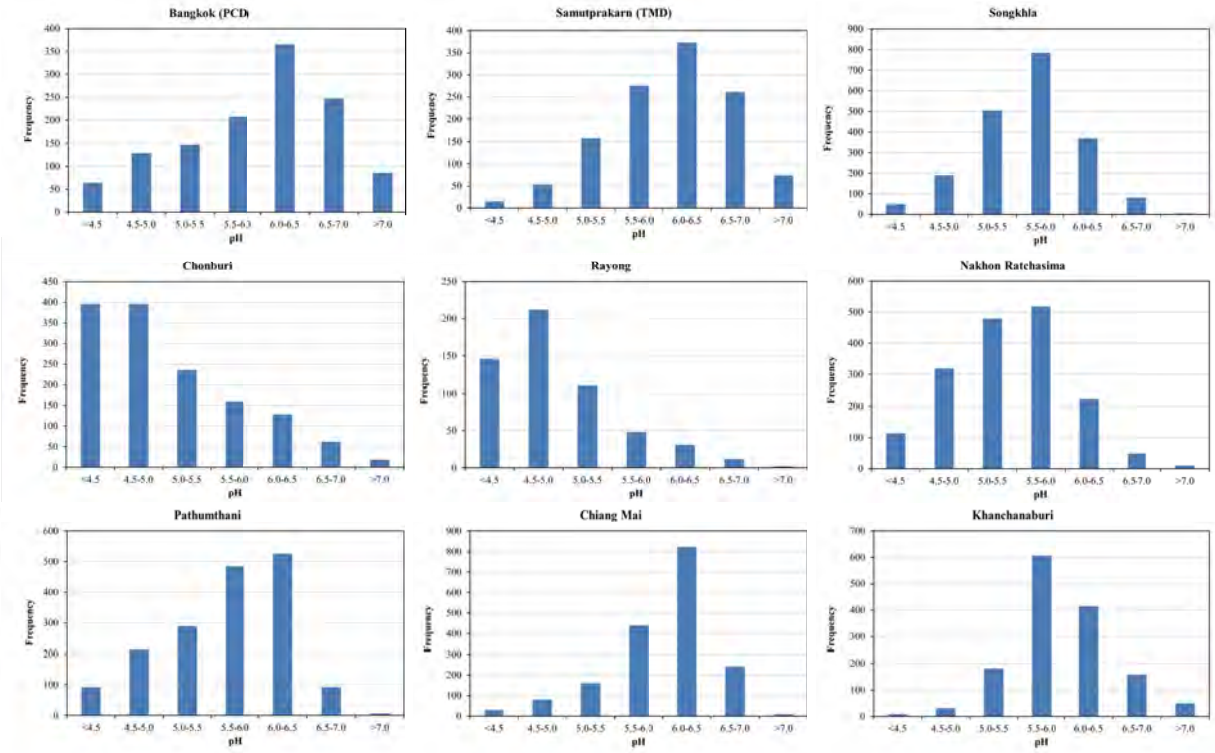


Figure 5. pH frequency distribution for the monitoring sites in Thailand during 2000-2019.

SO_4^{2-} and NO_3^- ions are released from the strong acids, H_2SO_4, and HNO_3, and they are not involved in the neutralization reaction once dissociated. Because the concentrations of SO_4^{2-} and NO_3^- ions remain unchanged throughout the neutralization, the SO_4^{2-} and NO_3^- concentration are numerically identical to those of H_2SO_4 and HNO_3, respectively. The initial concentration of the H^+ ion is equal to the concentration sum of SO_4^{2-} and NO_3^-, which is termed *input acidity*, denoted as A_i in the following formula:

$$A_i = [nss\text{-}\ SO_4^{2-}] + [NO_3^-]$$

where concentrations are in the unit of eq mole L^{-1}. The parameter pA_i is defined in a similar manner to pH, as follows, and corresponds to the pH if no neutralization takes place after the initial formation of sulfuric and nitric acids.

$$pA_i = -log_{10}([nss\text{-}\ SO_4^{2-}] + [\ NO_3^-])$$

The pH and pAi are the indices providing information on acid and base balance in precipitation.

During the neutralization process, the pH increased with additional bases while the pAi remain constant throughout the process.

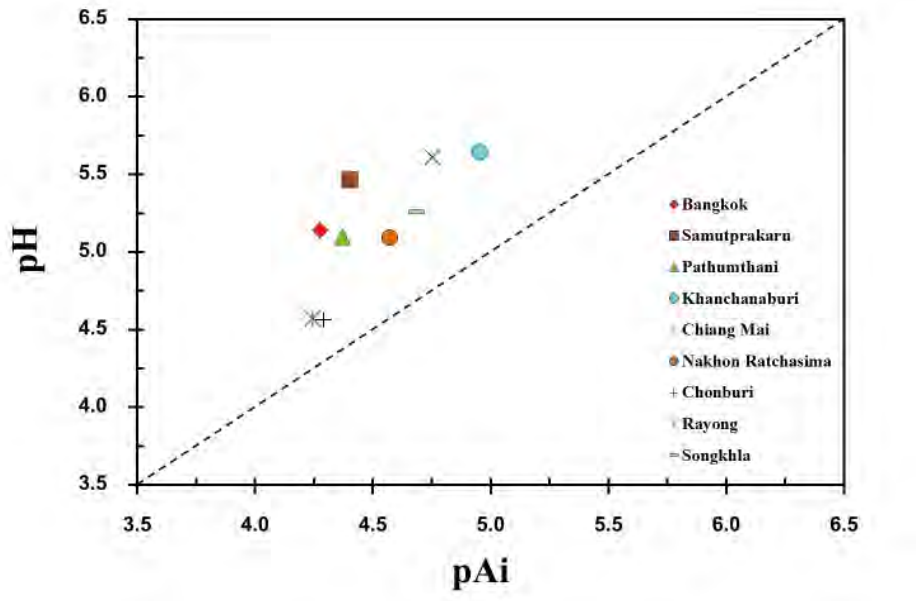


Figure 6. The pH-pAi diagram for annual mean of monitoring sites in Thailand during 2000-2019.

Figure 6. shows a relation between five-year annual mean pH and pAi for the monitoring sites in Thailand from 2000-2019. It was found that all sites plot is successfully located on or above the diagonal line of the pH-pAi diagram, in which pH is equal to pAi. The pH and pAi respectively ranged from 4.56-5.64 and 4.25-4.95. This overshooting of pH values was caused by the existence of an appreciable amount of bases such as $CaCO_3$ and NH_3.

In acid deposition chemistry, Nitric acid and Sulphuric acid are the two important acids. The relative contribution of these two acids is evaluated in the terms of corresponding anions, NO_3^- and nss-SO_4^{2-}. Knowing the ratio of the two acids is useful in identifying major acidifying substances. Nitric and sulphuric acids play an exclusively important role in acidification of the atmosphere and ecology although some significant roles are played by some other acids. The NO_3^- and nss-SO_4^{2-} are so stable that they are free from further acid-base interactions. The relative contribution for the entire concentration range for the two anions can be determined in the form of NO_3^- fraction for the sum of the ion pair, NO_3^- and nss-SO_4^{2-}: $[NO_3^-]/ ([NO_3^-] + [\text{nss-}SO_4^{2-}])$, which is denoted as fraction #1or F1 for simplicity.

$$F1 = [NO_3^-] / ([\ \text{nss-}SO_4^{2-}] + [\ NO_3^-])$$

The F1 was calculated for the twenty-years weighted average from 2000-2019 for all sites in Thailand as shown in Figure 7. It was found that at all sites the F1 values were lower than 0.5 which means H_2SO_4 was more significant than HNO_3 in acidification of rain. The maximum, 0.49, occurred at Pathumthani and followed by 0.48, 0.47, 0.46, 0.44, 0.43, 0.38, 0.28 and 0.25 for Chiang Mai, Nakhon Ratchasima, Bangkok, Songkhla, Kanchanaburi, Samutprakarn, Chonburi and

Rayong, respectively. The lowest ratio was found at 0.25 for Rayong, where H_2SO_4 was two times dominant acid than HNO_3 on an equivalent basis.

Whereas F1 could focus on the two acids, a similar discussion would be applicable to a pair of two basic compounds, NH_3 and $CaCO_3$. In precipitation samples, these compounds would be represented by NH_4^+ and nss-Ca^{2+}, which suggested defining a fraction, F2, to assess the importance of atmospheric NH_3 relative to $CaCO_3$ as:

$F2 = [NH_4^+] / ([\ nss\text{-}Ca^{2+}] + [NH_4^+])$

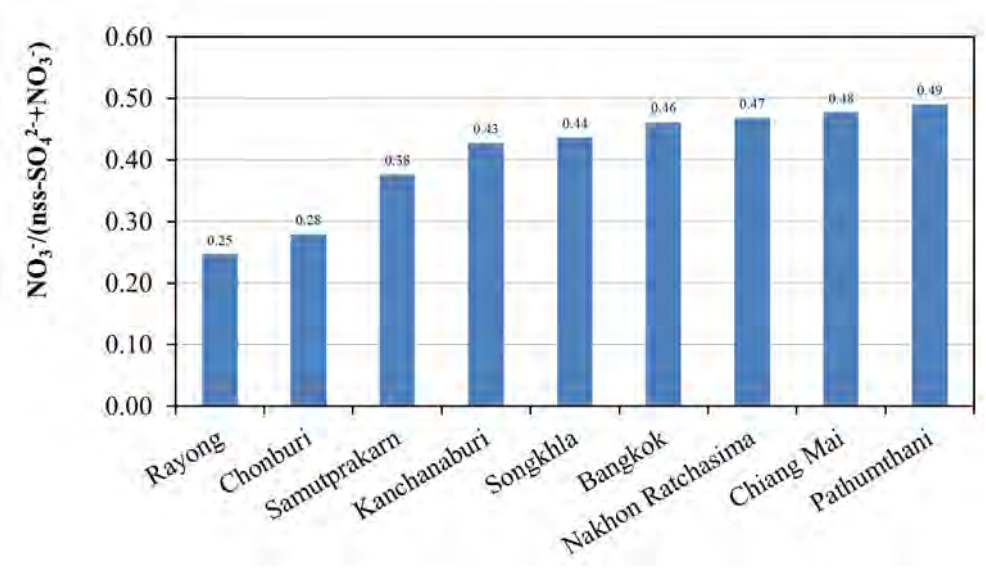


Figure 7. Equivalent fraction of Nitrate; $[NO_3^-]/([\ nss\text{-}SO_4^{2-}]+[\ NO_3^-])$.

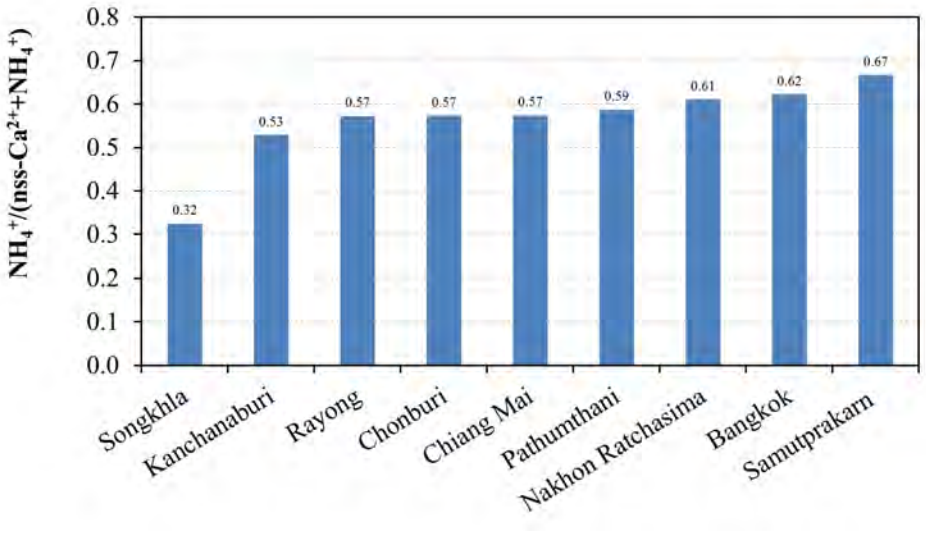


Figure 8. Equivalent fraction of Ammonium; $[NH_4^+]/([\ nss\text{-}Ca^{2+}] + [NH_4^+])$.

Figure 8. displays F2 ratio for the twenty-years weighted average in order of the increasing ratio. The values for F2 are in a wide range from 0.32 to 0.67. Most of the ratios are greater than 0.50

where the two compounds equally work as bases in the interaction. It was found that eight out of nine sites had shown F2 greater than 0.50, which are Samutprakarn, 0.67; Bangkok, 0.62; Nakhon Ratchasima, 0.61; Pathumthani, 0.59; Chiang Mai, 0.57; Chonburi, 0.57; Rayong, 0.57 and Khanchanaburi, 0.53. For these sites, ammonia is the dominant base in comparison with $CaCO_3$. Another site in Songkhla had shown F2 less than 0.5 indicated that $CaCO_3$ is the dominant base.

The twenty-years average annual deposition of nss-SO_4^{2-} and NO_3^- (2000-2019) in Thailand is illustrated in Figure 9. The deposition of nss-SO_4^{2-} are in range from 3.95 - 26.61 mmol/m^2/y. The highest amount of nss-SO_4^{2-} was found at Rayong (urban site, industrial area), with an annual flux about 26.61 mmol/m^2/y and the lowest amount was found at Khanchanaburi (remote site), with an annual flux about 3.95 mmol/m^2/y. The deposition of NO_3^- are in range from 5.92 - 36.37 mmol/m^2/y. The highest amount of NO_3^- was found at Bangkok (urban site, city area), with an annual flux about 36.37 mmol/m^2/y and the lowest amount was found at Khanchanaburi, with an annual flux about 5.92 mmol/m^2/y. It was clearly seen that at monitoring site located in the industrial areas such as Rayong and Chonburi, the annual deposition of nss-SO_4^{2-} were found much more than NO_3^- . The higher sulfate deposition might have been contributed from the high SO_2 emissions from industrial fossil fuel combustion.

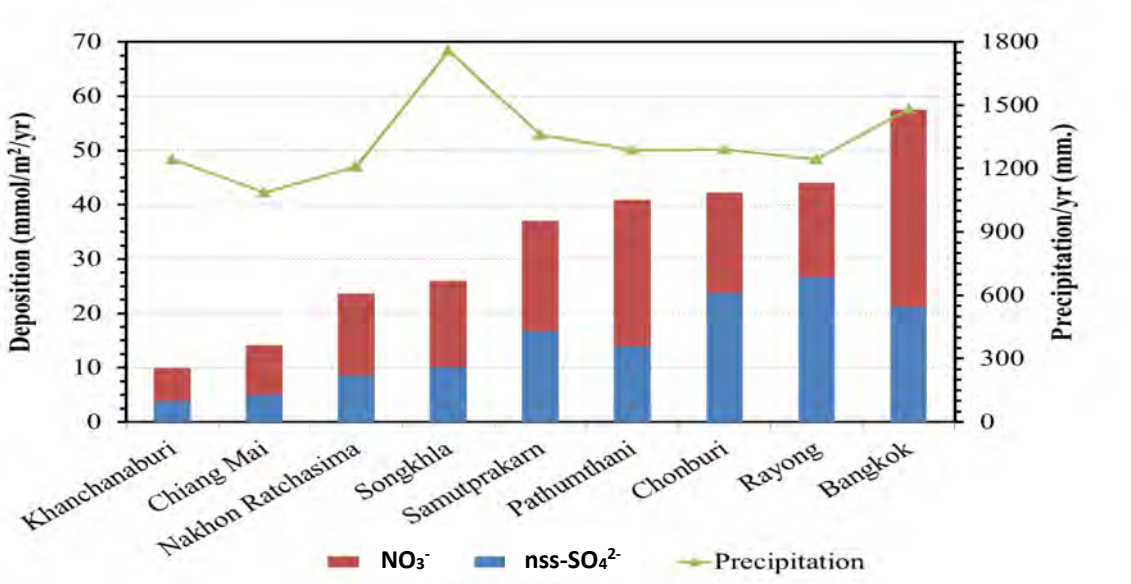


Figure 9. Five-year average annual deposition of nss-SO_4^{2-} and NO_3^- (2000-2019).

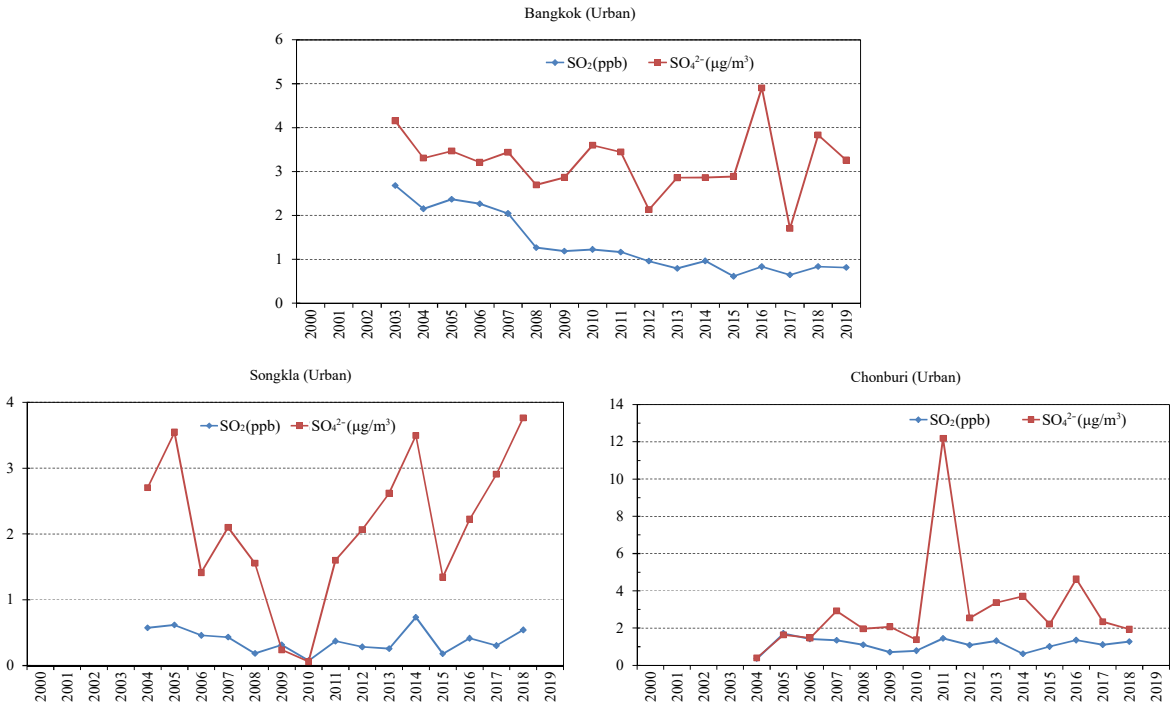
2.2 State of dry deposition

To assess total acid deposition, the dry deposition follows the wet deposition criterion which twenty-years data (2000 - 2019) of EANET are assessed and all dry deposition monitoring sites are located within the vicinity of the wet deposition monitoring. The analysis will be presented in terms of annual concentration variation and topographical differences (urban, rural and remote sites). The principal acid chemicals for analyses consist of the gas components: SO_2, HNO_3, NH_3 and aerosol components: SO_4^{2-}, NO_3^- and NH_4^+. The following analysis is based on filter pack samples.

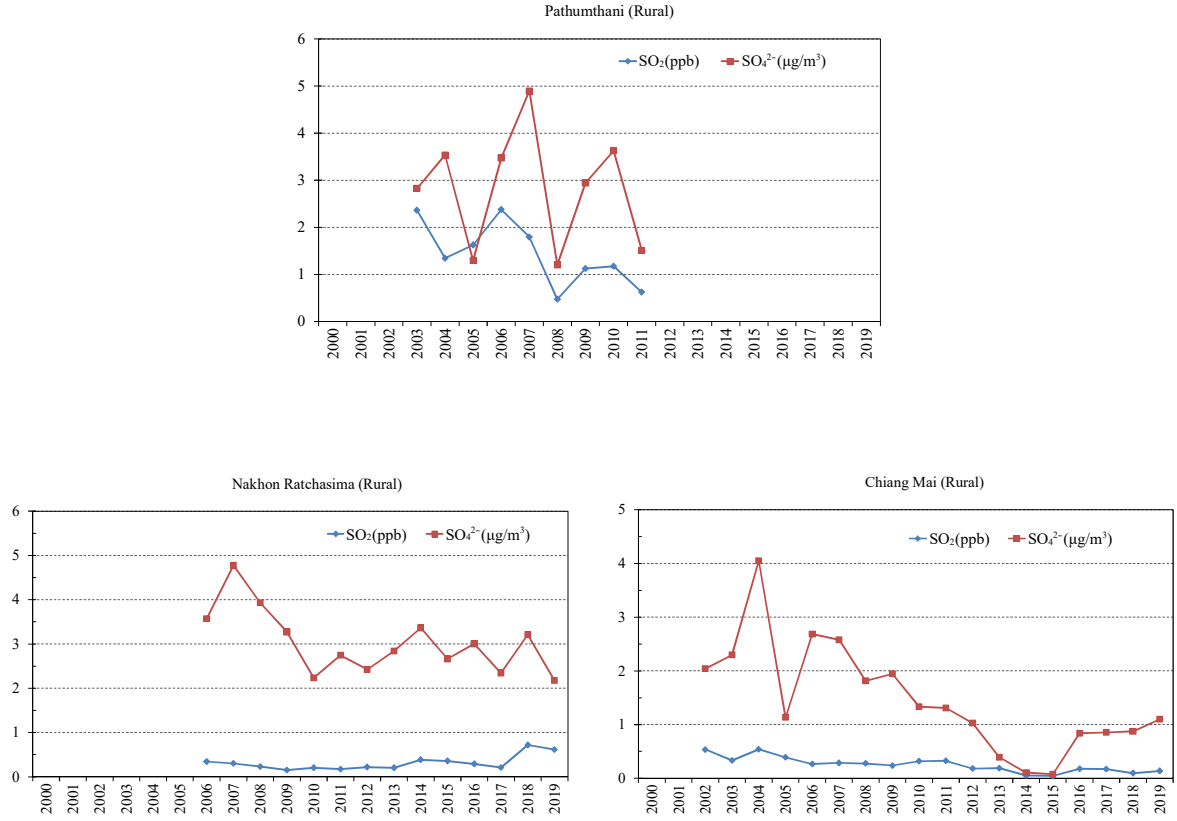
Gas and aerosol concentrations of sulfur

The gaseous SO_2 and aerosol SO_4^{2-} are the principal man-made acid species affecting neutrality of the atmosphere. The status trends of these acid concentrations during 2000 - 2019 in the urban, rural and remote areas are presented in Figure 10. The yearly SO_2 concentrations in the urban sites are shown in Figure 10(a), were found in the ranges of 0.61 - 2.68 ppb, 0.07-0.73 ppb and 0.36-1.71 ppb in Bangkok, Songkla and Chonburi, respectively. High concentrations were found in the dry season (September - February) and low concentrations were found in the wet season (June – August). The low concentrations are considered to be affected by atmospheric wash-off such as heavy rainfall in the tropical climate. The SO_4^{2-} concentration follows the same decreasing trend as SO_2. The SO_4^{2-} concentrations were observed in high values in the dry season and relatively low in the wet season. The yearly concentrations of SO_4^{2-} of urban sites were in the range of 1.70-4.91 $\mu g/m^3$, 0.06-3.76 $\mu g/m^3$ and 0.40-12.18 $\mu g/m^3$ in Bangkok, Songkhla and Chonburi, respectively.
The yearly SO_2 concentrations in the rural sites are shown in Figure 10(b), were observed in the ranges of 0.47-2.38 ppb, 0.15-0.72 ppb and 0.04-0.54 ppb in Pathumthani, Nakhon Ratchasima and Chiang Mai, respectively. The observed values of SO_4^{2-} concentrations were in the ranges of 1.20- 4.89 $\mu g/m^3$, 2.17-4.78 $\mu g/m^3$ and 0.07-4.05 $\mu g/m^3$ in Pathumthani, Nakhon Ratchasima and Chiang Mai, respectively.

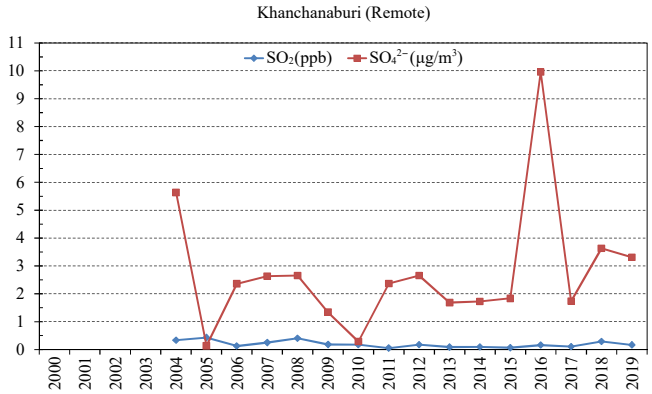
The yearly concentration of SO_2 in the remote site, as shown in Figure 10(c), was observed in the ranges of 0.05 - 0.43 ppb in Khanchanaburi. The SO_4^{2-} concentrations were found in the ranges of 0.14-9.96 $\mu g/m^3$ in Khanchanaburi.


Bangkok (Urban)
SO2(ppb)
SO4 2-(µg/m3)
Songkla (Urban)
SO2(ppb)
SO4 2-(µg/m3)
Chonburi (Urban)
SO2(ppb)
SO4 2-(µg/m3)

(a)


Pathumthani (Rural)
SO2(ppb)
SO4 2-(µg/m3)
Nakhon Ratchasima (Rural)
SO2(ppb)
SO4 2-(µg/m3)
Chiang Mai (Rural)
SO2(ppb)
SO4 2-(µg/m3)

(b)



(c)

Figure 10. The annual variation in concentrations of gaseous SO_2 and aerosol during twenty-years monitoring (2000 - 2019). (a) Bangkok, Songkla and Chonburi sites (urban), (b) Chiang Mai, Nakhon Ratchasima and Patumthani sites (rural) and (c) Khanchanaburi sites (remote).

Gas and aerosol concentrations of nitrogen

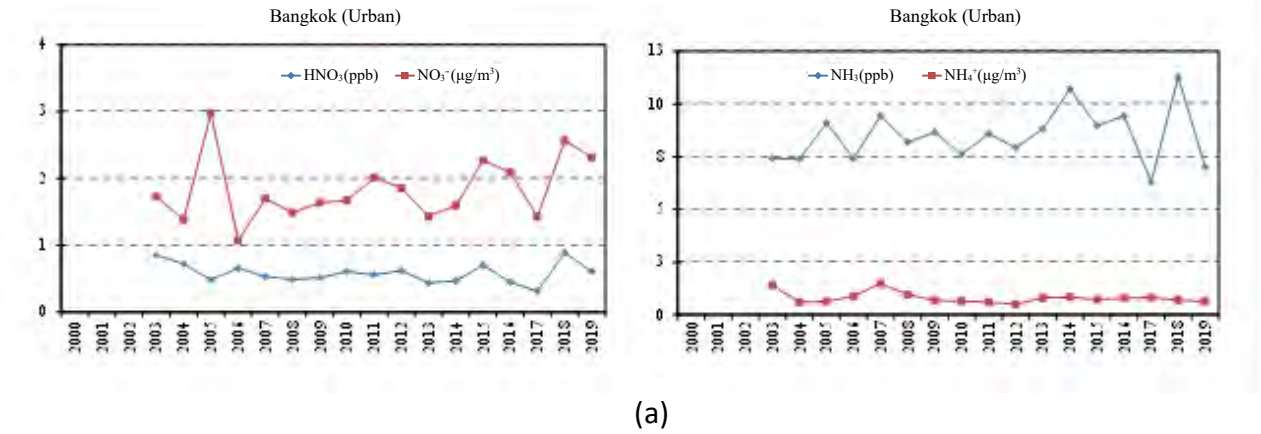
The principal chemical species of nitrogen, due to acidic nature, compose of gases, HNO_3 and NH_3 and aerosols, NO_3^- and NH_4^+. The observed values of these chemicals were shown distinguishable trend of high and low concentration in the dry and the wet season.

The yearly concentrations of gaseous HNO_3 and NH_3 in urban sites are shown in Figure 11(a)-11(c). It was found that the HNO_3 concentrations were in the ranges of 0.31-0.89 ppb, 0.04-0.42 ppb and 0.03-2.16 ppb in Bangkok, Songkhla and Chonburi, respectively. While the yearly concentrations of NH_3 were in the ranges of 6.31-11.29 ppb, 0.61-30.24 ppb and 0.84-18.66 ppb in Bangkok, Songkhla and Chonburi, respectively. The concentration of NH_3 was significantly 8-40 times higher than HNO_3. The sources of NH_3 emission in the urban area are envisaged to arise from nearby industrial wastewater and sewage treatments and agriculture utilizing fertilizers. The yearly concentrations of aerosol NO_3^- were observed in the ranges of 1.07-2.98 µg/m^3, 0.07-1.64 µg/m^3 and 0.13-10.89 µg/m^3 in Bangkok, Songkhla and Chonburi, respectively. It was also observed that yearly concentrations of NH_4^+ in the urban sites were in the ranges of 0.50-1.48 µg/m^3, 0.06-0.88 µg/m^3 and 0.03-4.20 µg/m^3 in Bangkok, Songkhla and Chonburi, respectively. The trend of both gases (NO_3 and NH_4^+) appeared steady during the past 20 years and the maximum value was observed during the dry season and the minimum value was observed during the wet season. The observed low concentration was supposed to be resulted from the atmospheric wash out by heavy rainfall.

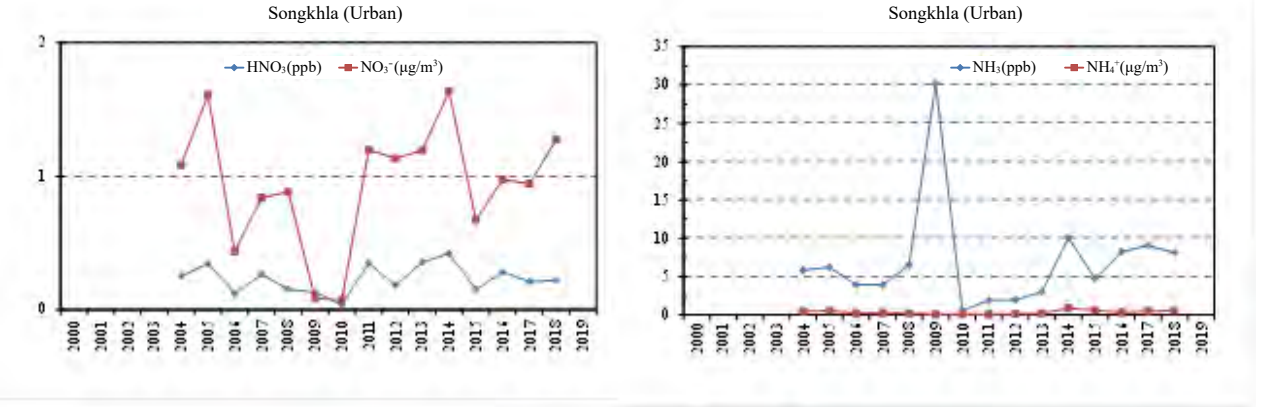
In the rural areas of Nakhon Ratchasima, the concentrations of gaseous HNO_3 and NH_3 were found in the ranges of 0.10 – 0.35 ppb and 1.84 – 5.76 ppb, respectively. The concentrations of aerosol NO_3^- and NH_4^+ were in the ranges of 0.18 – 0.58 μg/m^3 and 0.76 – 1.60 μg/m^3, respectively. See Figure 11(d).

In the rural areas of Chiang Mai and Pathumthani, the concentrations of gaseous HNO_3 were found in the ranges of 0.04 - 1.95 ppb and 0.29 – 1.08 ppb, and the concentrations of NH_3 were found in the ranges of 0.89 – 9.06 ppb and 2.75 – 9.78 ppb respectively. The concentrations of aerosol NO_3^- of Chiang Mai and Pathumthani were found in the range of 0.11 – 9.89 μg/m^3 and 0.69 – 2.06 μg/m^3, and NH_4^+ was in the ranges of 0.09 – 3.64 μg/m^3 and 0.21 – 1.46 μg/m^3, respectively. These observed data also show significant trend of high NH_3 concentration in the rural areas. See Figure 11(e) and (f).

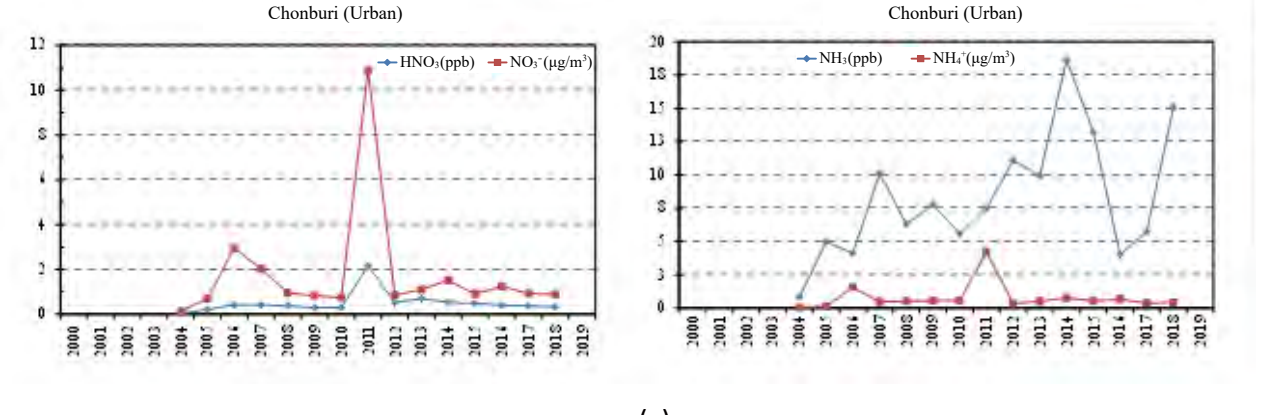
In the remote areas of Khanchanaburi, the concentrations of gaseous HNO_3 and NH_3 were found in the ranges of 0.01 – 1.17 ppb and 1.54 – 5.82 ppb, respectively. The concentrations of aerosol NO_3^- and NH_4^+ were in the ranges of 0.03 – 3.18 μg/m^3 and 0.05 – 1.80 μg/m^3, respectively. The remote site was also shown high values of NH_3. It should be noted that the existence of high NH_3 in the atmosphere can be a normal occurrence in the agricultural country. See Figure 11(g).


Bangkok (Urban)
HNO3(ppb)
NO3-(µg/m3)
Bangkok (Urban)
NH3(ppb)
NH4+(µg/m3)

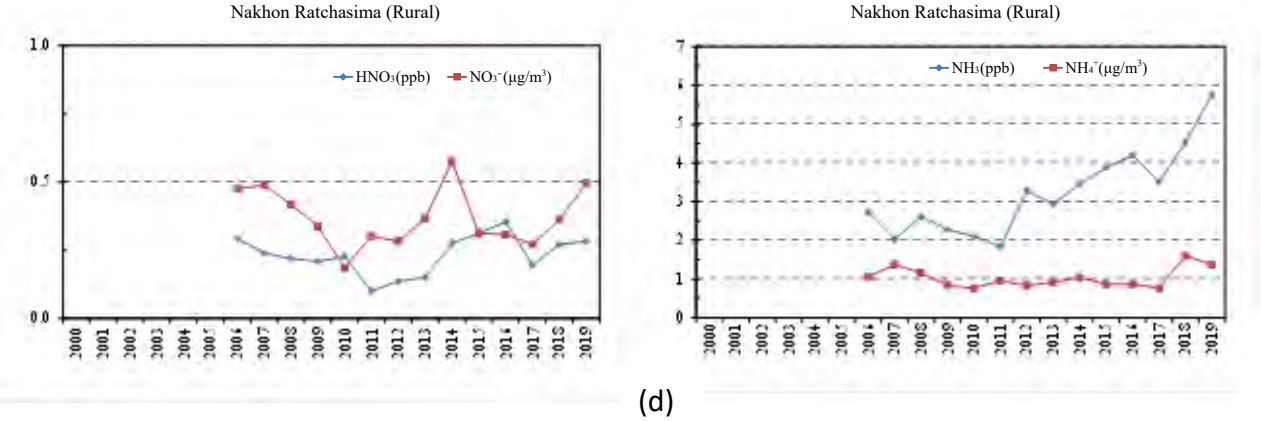
(a)


Songkhla (Urban)
HNO3(ppb)
NO3-(µg/m3)
Songkhla (Urban)
NH3(ppb)
NH4+(µg/m3)

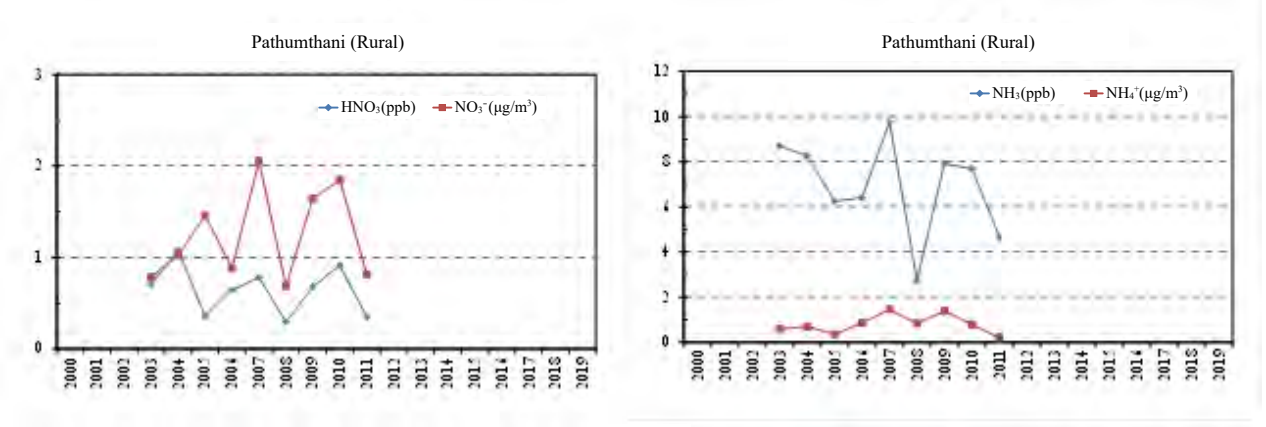
(b)


Chonburi (Urban)
HNO3(ppb)
NO3-(µg/m3)
Chonburi (Urban)
NH3(ppb)
NH4+(µg/m3)

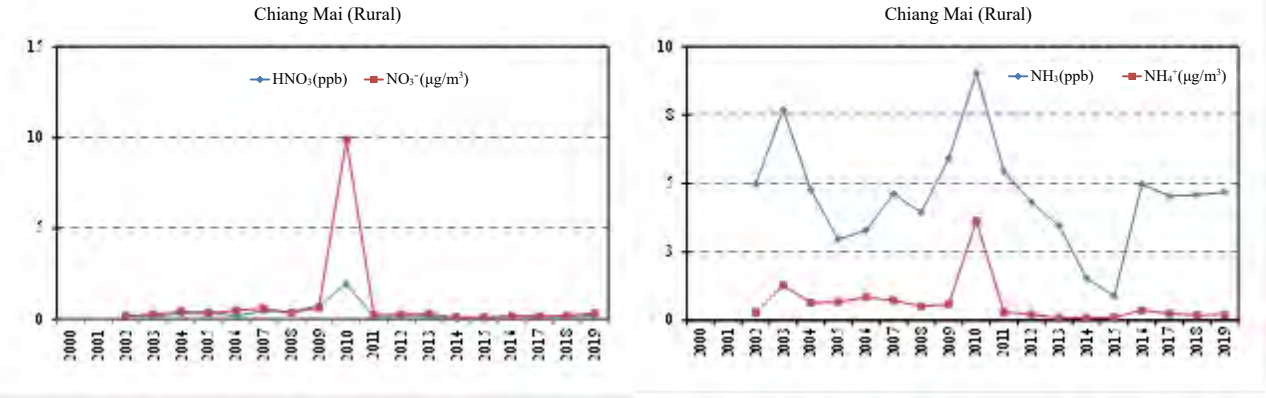
(c)


Nakhon Ratchasima (Rural)
HNO3(ppb)
NO3-(µg/m3)
Nakhon Ratchasima (Rural)
NH3(ppb)
NH4+(µg/m3)

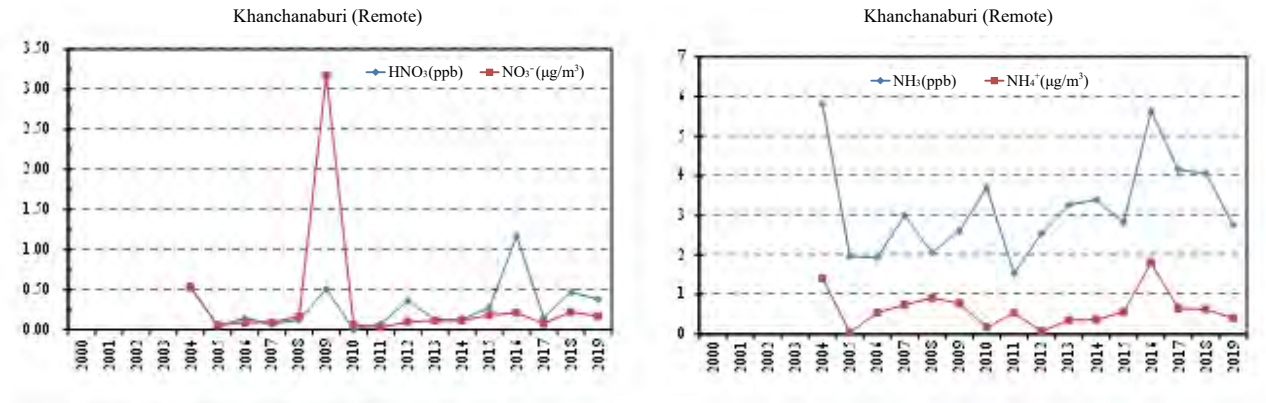
(d)



(e)



(f)



(g)

Figure 11. The annual variation in concentrations of gaseous HNO_3, NH_3 and aerosol NO_3^- and NH_4^+ during twenty-years monitoring (2000 - 2019). (a) Bangkok site (urban), (b) Songkhla (urban), (c) Chonburi site (urban), (d) Nakhon Ratchasima site (rural), (e) Pathumthani site (rural), (f) Chiang Mai site (rural) and (g) Khanchanaburi site (remote).

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National Assessment on Acid Deposition in Vietnam





Vietnam Institute of Meteorology, Hydrology and Climate change

2021

Chapter 1. Basic information on National Monitoring Activities

1.1. Outline of the activities on acid deposition and National Monitoring plan

Acid deposition is the process by which acidic substances, such as sulphuric acid and nitric acid, in the atmosphere fall into the earth's surface. The atmospheric deposition of acidic substances to the earth surface is categorized into two forms, namely wet deposition and dry deposition. Wet deposition happens when the sulfuric and nitric acids formed in the atmosphere fall to the ground mixed with rain, snow, fog, or hail. This is what we usually think of acid rain. Dry deposition is the precipitation of acidic particles and gases from the atmosphere in the absence of moisture.

SO_2 and NOx emissions from human activities, such as burning fossil fuels, and crude oil production and refining, are the main causes of acid deposition. In the face of rapid industrialization in the world in general and Vietnam in particular, the increased use of fossil fuels is causing the risk of serious air pollution and increasing the environmental threat of acid deposition. Acid deposition is considered as one of the serious environmental pollution problems not only because of its impacts on human life and the ecosystem but also because of the fact that acid deposition and air pollution are trans-boundary issues that need integrated global actions to control.

The Acid Deposition Monitoring Network in East Asia (EANET) has become a leading acid deposition monitoring network in East Asia region since 1998, initiated and established by Japan as a regional cooperation initiative to enhance efforts to protect the environment and human health in the East Asia region. Vietnam has officially joined the EANET since August 1999 and the Institute of Meteorology, Hydrology and Climate Change (IMHEN) is Vietnam's national focal point in the EANET network.

Currently, in Vietnam, there are 3 acid deposition monitoring networks run and managed by different agencies and research institutions. Brief introduction of these networks are presented as follows.

- **Acid deposition monitoring station system under EANET network** managed by IMHEN. Currently, there are 7 acid deposition monitoring stations operated under EANET framework

monitoring both dry and wet depositions. According to EANET criteria, these stations are categoried into three groups, namely remote, rural, and urban. They are located in Hanoi, Hoa Binh, Yen Bai, Da Nang, Cuc Phuong, Ho Chi Minh city, and Can Tho.

- **National network of Hydro-Meteorological stations** belong to Vietnam Meteorological and Hydrological Administration: The network of Hydro-meteorological stations is the largest and oldest network of stations in Vietnam, including 23 rainwater monitoring stations which installed in Meteorological stations over the country and started operating since 1980.
- **Acid rain monitoring network** belong to the National Environmental Monitoring Network: This network consists of 18 monitoring points installed since 1998, mainly at meteorological stations in all three regions (North, Central and South) of Vietnam.

The current systems of acid deposition monitoring stations in Vietnam were established and operated based on specific requirements of each line ministry/ agency, so they also have different characteristics of those ministries/ agencies. Their equipment, procedures and methods of acid deposition monitoring are not synchronized and overlapped.

In 2016, the Prime Minister approved the master plan on the national environmental and natural resource monitoring network for the period 2016 - 2025, with a vision to 2030, including contents related to acid deposition monitoring. According to the master plan, Vietnam will install new monitoring stations including 7 automatic air environment monitoring stations, 12 periodical air environment monitoring points; consolidate 18 existing acid rain stations and will establish 5 new acid rain monitoring stations, bringing the total number of acid rain monitoring stations to 23 by 2030. Thus, acid deposition monitoring activities in Vietnam are synchronously and uniformly planned and will be invested to operate more effectively in the future.

1.2 EANET acid deposition monitoring stations

In 1999, with the support of equipment and machines (two wet only samplers and two filter packs) from Japan Government, 2 acid deposition monitoring stations located in Lang (in Hanoi city) and Hoa Binh (in Hoa Binh province) were set up and have been operated since then. In 2008, with the agreement of Vietnam Government, Ministry of Natural Resource and Environment added 2 existing sites: Cuc Phuong station (in Ninh Binh province), Da Nang station (in Da Nang city) of National network of Hydro-Meteorological stations into EANET network; and then more 3 new sites also were setup including Ho Chi Minh station (in HCM city) and Can Tho station (in Can Tho province) in 2014 and Yen Bai station in August 2015. Monitoring data has been submitted to Network Center of EANET helping and used as the scientific information for the evaluation of both acid depositions and its impacts on ecosystems in East Asia. The location and outline of EANET sites in Vietnam are shown in the Figures 1.1 - 1.8 and Table 1.

Figure 1. 1. The location of EANET monitoring stations in Vietnam.

Table 1 EANET acid deposition monitoring sites in Vietnam

Deposition type	Site characteristic	Place	Sampler	Starting of operation	Laboratory
Wet deposition	Urban sites (3 sites)	Ha Noi	Wet only sampler	1999	Environmental Laboratory - Center for Environmental Research - IMHEN-MONRE
		Da Nang	Wet sampler with pH, EC automatic measurement for each mm of rainfall	2008	Environmental analysis laboratory II area- Mid-central regional Hydro-meteorological center – National Hydro-meteorological Administration (NHMS) – MONRE
		Ho Chi Minh city	Wet only sampler	2014	Environmental Laboratory - Sub-Institute of Hydro-Meteorology and Climate

					Change (SIHYMECC) – IMHEN- MONRE
	Rural sites (3 sites)	Hoa Binh	Wet only sampler	1999	Environmental Laboratory - Center for Environmental Research - IMHEN- MONRE
		Can Tho*	Wet only sampler	2014	Environmental Laboratory - Sub-Institute of Hydro-Meteorology and Climate Change (SIHYMECC) – IMHEN- MONRE
		Yen Bai	Wet only sampler	2015	Environmental Laboratory - Center for Environmental Research - IMHEN- MONRE
	Remote sites (1 site)	Cuc Phuong	Wet sampler with pH, EC automatic measurement for each mm of rainfall	2008	Environmental analysis laboratory I area - Center for Hydro-Meteorological and Environmental Networks - National Hydro-meteorological Administration (NHMS) – MONRE
Dry deposition	Urban sites (2 sites)	Ha Noi,	Filter Pack	1999	Environmental Laboratory - Center for Environmental Research - IMHEN- MONRE
		Ho Chi Minh*	Filter Pack	2014	Environmental Laboratory - Sub-Institute of Hydro-Meteorology and Climate Change (SIHYMECC) – IMHEN- MONRE
	Rural sites (3 sites)	Hoa Binh	Filter Pack	1999	Environmental Laboratory - Center for Environmental Research - IMHEN- MONRE
		Can Tho*	Filter Pack	2014	Environmental Laboratory - Sub-Institute of Hydro-Meteorology and Climate Change (SIHYMECC) – IMHEN- MONRE
		Yen Bai	Filter Pack	2015	Environmental Laboratory - Center for Environmental Research - IMHEN- MONRE
Inland aquatic environment	Rural sites (1 sites)	Hoa Binh		1999	Environmental Laboratory - Center for Environmental Research - IMHEN- MONRE

a

b

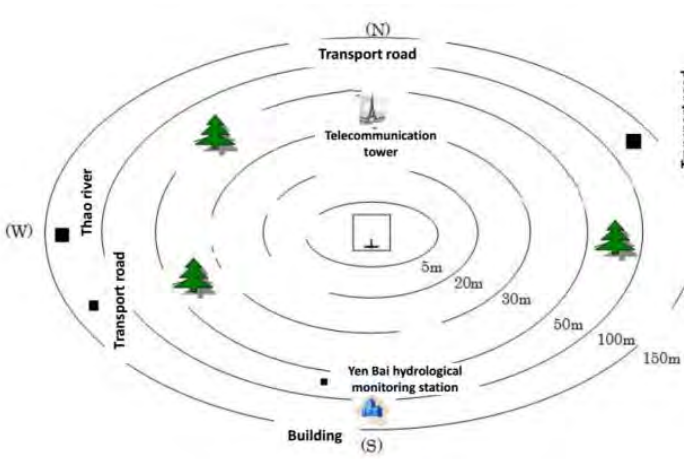


Figure 1. 2. (a) Picture of Yen Bai station and (b) outline of Yen Bai station: on-site scale (distance within 150m).

a

b

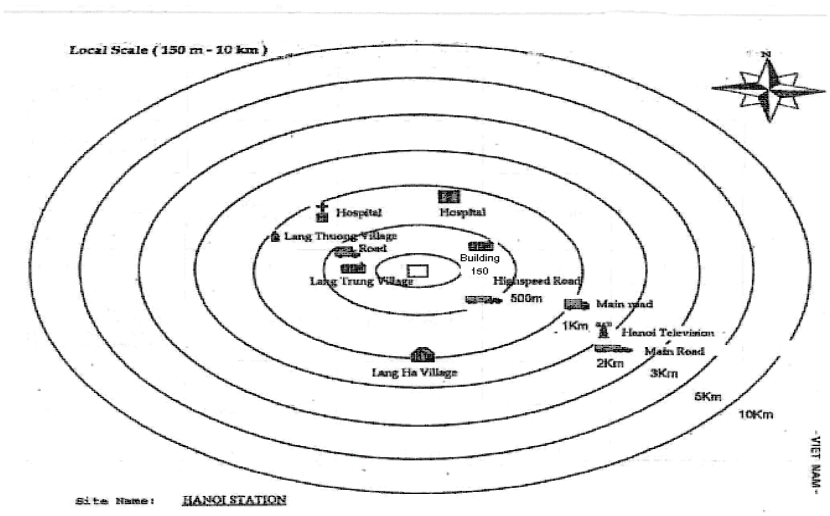


Figure 1. 3. (a) Picture of Ha Noi station and (b) outline of Hanoi station: local scale (distance 150m- 10km).

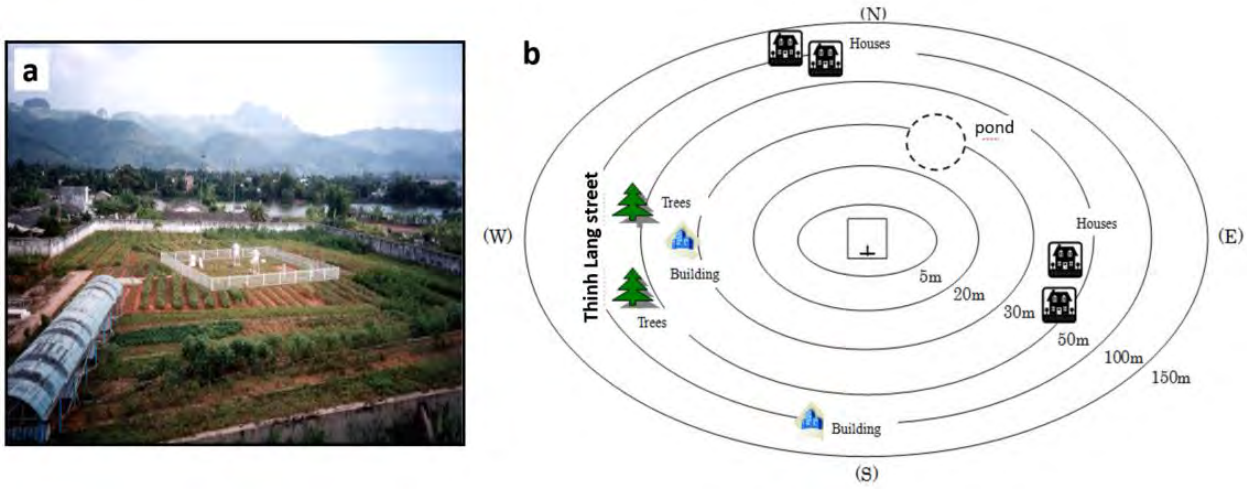


Figure 1. 4. (a) Picture of Hoa Binh station and (b) outline of Hoa Binh station: on-site scale (distance within 150m).

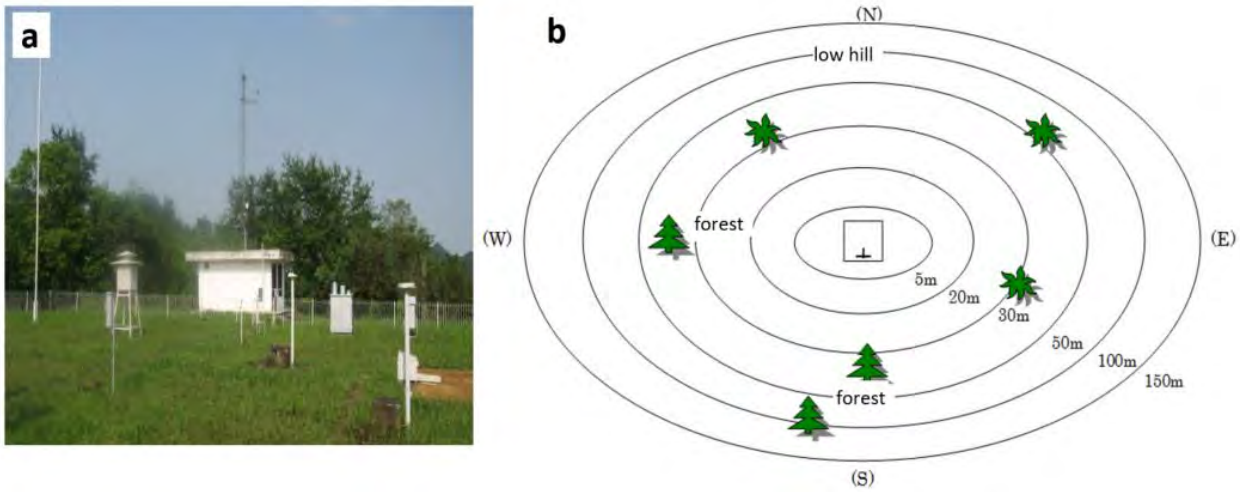


Figure 1. 5. (a) Picture of Cuc Phuong station and (b) outline of Cuc Phuong station: on-site scale (distance within 150m).

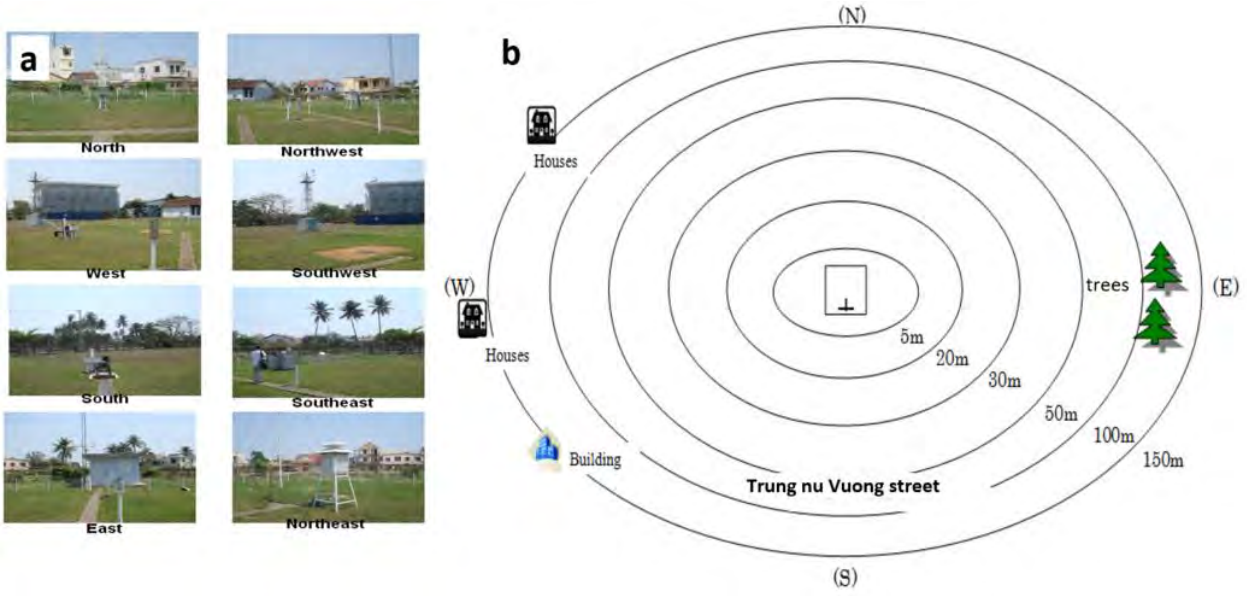


Figure 1. 6. (a) Picture of Da Nang station and (b) outline of Da Nang station on-site scale (distance within 150m).

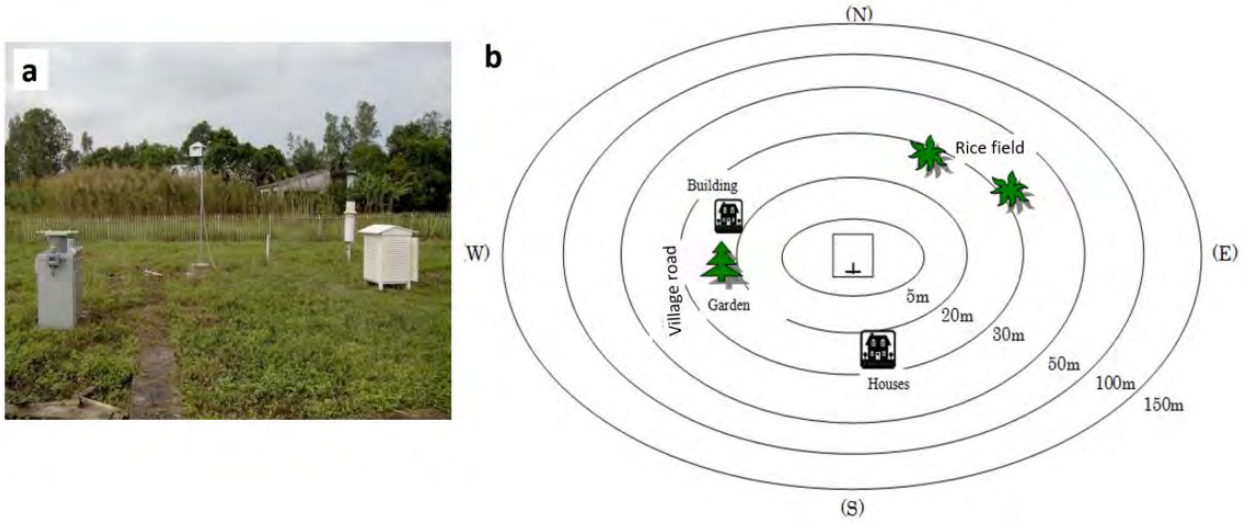


Figure 1. 7. (a) Picture of Can Tho station and (b) outline of Can Tho station on-site scale (distance within 150m).

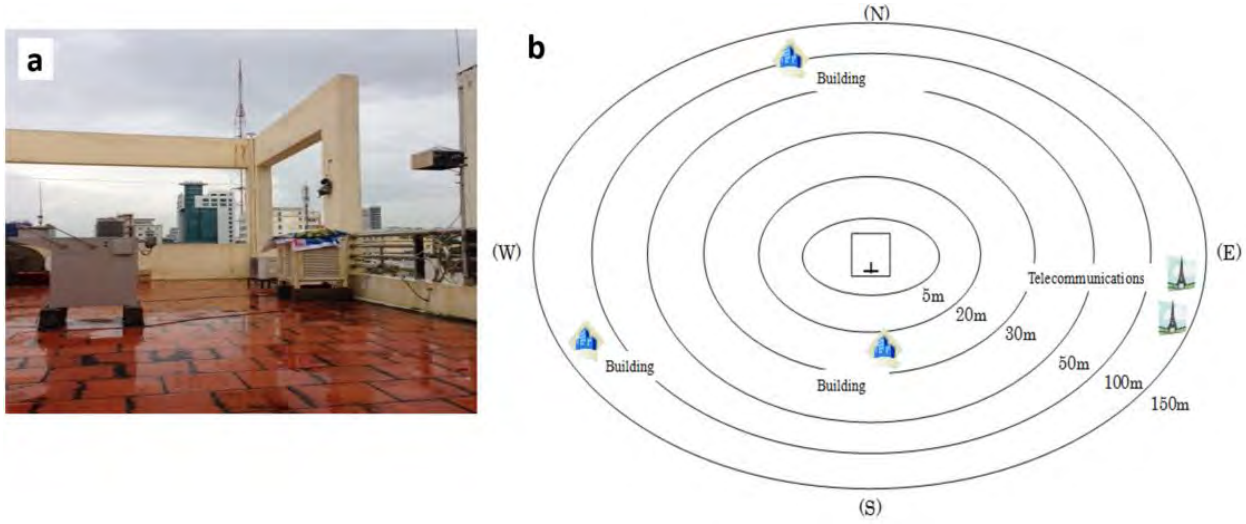


Figure 1. 8. (a) Picture of Ho Chi Minh station and (b) outline of Ho Chi Minh station on-site scale (distance within 150m).

1.3 Sampling and measurements

1.3.1 Wet deposition monitoring

Acid deposition monitoring in Vietnam has been conducted according to the common methodologies specified in the "Technical Documents for Wet deposition Monitoring in East Asia" in order to obtain the equivalent quality of monitoring data. The samples were monitored in 24 hours, from 9:00 am to 9:00 am of next day and weekly composite samples can be analyzed in Ha Noi, Hoa Binh, Ho Chi Minh, and Can Tho sites. Samples are taken in every precipitation event in Da Nang, Cuc Phuong sites and pH, EC was automatic measured each mm of rainfall; These samples are the combination of 10-days from 2010 to 2012) and 7-days (weekly) samples from 2013 to now.

The monitoring parameters include: pH, EC, F-, Cl^-, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+, and NH_4^+; meteorological parameters (temperature, humidity, wind velocity, wind direction, rainfall, ultra-violet) and the analytical Method include: pH meter, EC meter, IC for anions and NH_4^+, Na+, AAS for cations.

1.3.2 Dry deposition monitoring

The dry deposition was monitored using Filter Pack method with monitoring interval of seven days, from 9:00 am Monday of this week to 9:00 am Monday of next week. The monitoring parameters include: Gases: SO_2, HCl, HNO_3, NH_3 and ions Cl^-, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+, and NH_4^+ in the aerosol. The analytical methods are pH meter, EC meter, IC for anions and NH_4^+, Na^+, AAS for cation. Figure 1.9 shows the Wet Sampler with pH, EC automatic measurement each mm of rainfall.

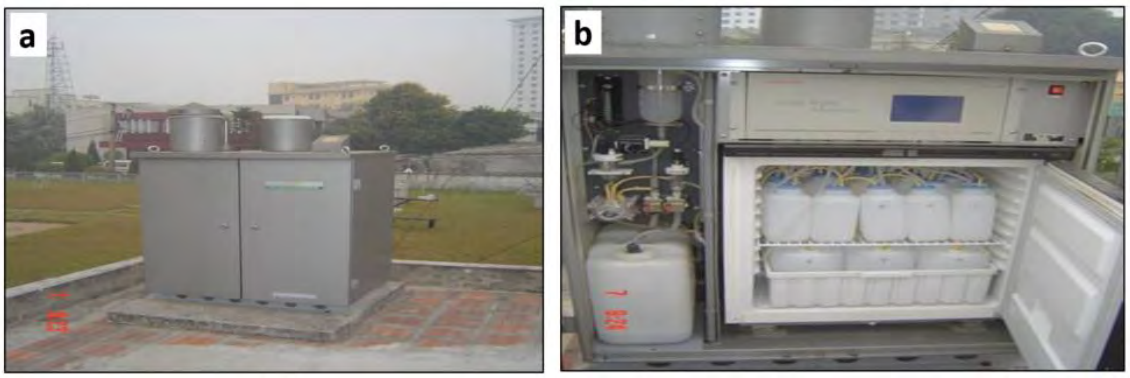


Figure 1. 9. Wet Sampler with pH, EC automatic measurement each mm of rainfall (Kimoto MCSAM-6-VB).

1.3.3 Inland aquatic environment

Inland aquatic environment were monitoring quarterly (4 times/year) with monitoring parameters include pH, EC, Cl^-, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+, alkalinity and COD, NO_2^-, clarity. Such parameters were analyzed with methods including pH meter, EC meter, IC for anions and NH_4^+, Na^+, AAS for cation, titration method for alkalinity at pH 4.8 endpoint, $KMnO_4$ method for COD and colorimetric method for NO_2^-. The Figure 1.10 shows some pictures of equipment for Acid Deposition Monitoring Analysis.

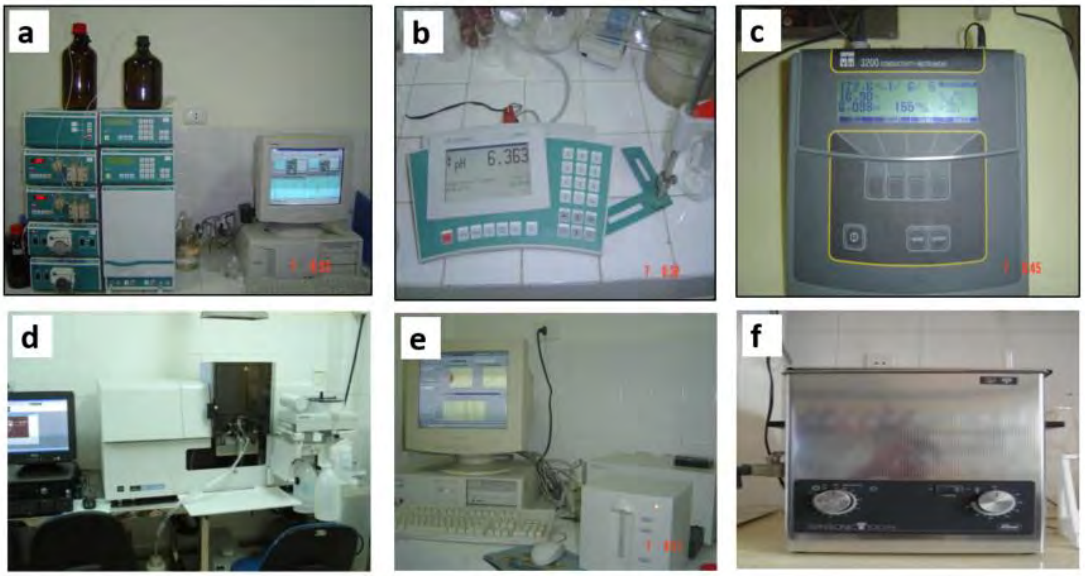


Figure 1. 10. Pictures of equipment for Acid Deposition Analysis (a) IC Metrohm Mic 3, (b) pH meter – 793, (c) EC meter – YSI 3200, (d) AAS800 of PerkinElmer, (e) UV-Vis system – HP8453 and (f) Ultrasonic bath.

Chapter 2. State of Acid Deposition in Vietnam

2.1 State of wet deposition

a) pH of rain water

In period of 2010 – 2019, the below 5.6 annual pH value was observed in some monitoring sites such as Hoa Binh, Cuc Phuong and Yen Bai. Especially, the annual average pH value in Yen Bai site is the lowest in the range from 4.8 – 5.4. This implied that acid rain has occurred frequently in Hoa Binh, Cuc Phuong and Yen Bai. In Hanoi site, the annual average pH values have dramatically fluctuated by years in range of pH from 4.9 to 6.5.

For 2 southern sites, Can Tho and Ho Chi Minh, all of annual average pH values are higher than 5.6 (see Fig. 2.1).

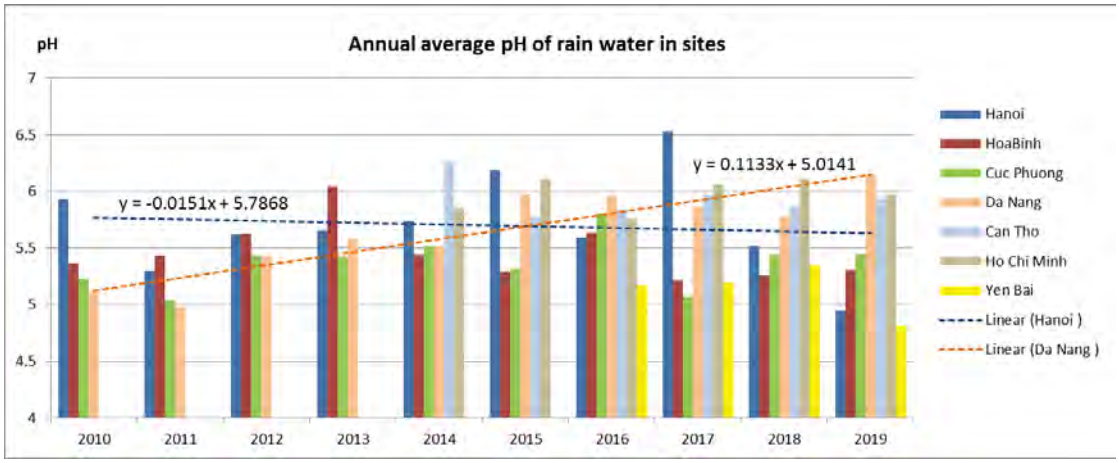
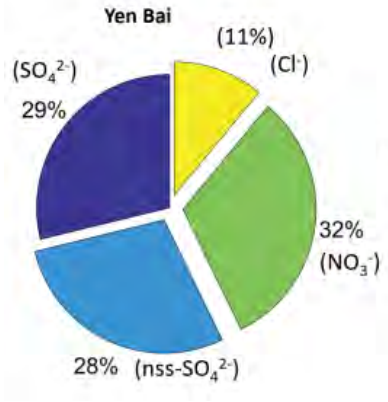


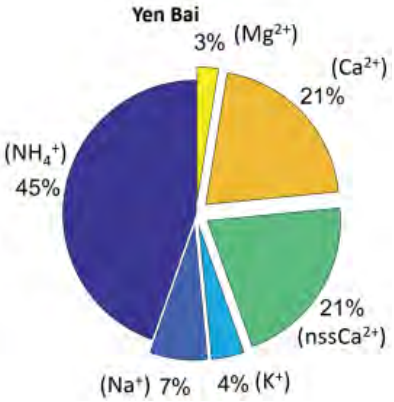
Figure 2.1. Graph of annual average pH of rainwater in sites (2010 – 2019).

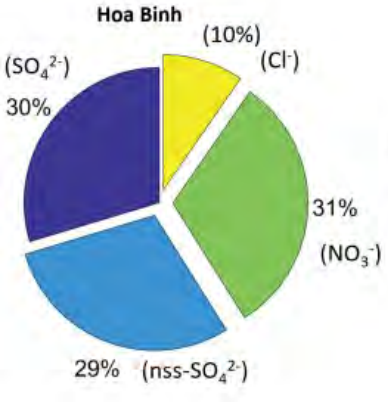
According to observation data from sites, in the period of 2010 – 2019, in general, annual rainfall of central and southern sites (Da Nang, Ho Chi Minh and Can Tho) are higher than the northern sites' (Hanoi, Hoa Binh, Yen Bai and Cuc Phuong), in range of 1500mm - 2700mm and 1200mm - 2300mm, respectively (presented in Fig 2.3-2.5). It is notable that the annual rainfall in Da Nang site was at record high of 3639mm in 2011, however, its annual average pH is lowest (pH= 5,0) in comparing with its other years (see Figure 2.1).

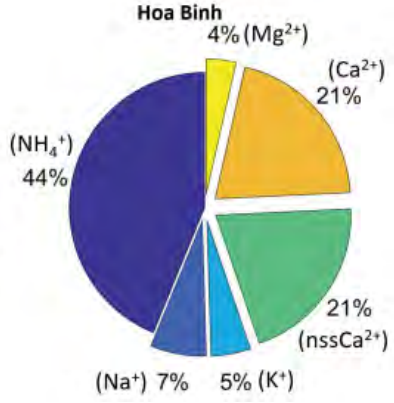
b) Ion composition in rain water

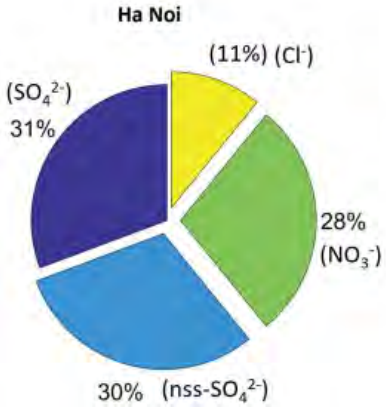
Chemical composition analysis of rainwater samples showed that SO_4^{2-}, NO_3^-, NH_4^+, Ca^{2+} ions are predominant in ionic composition of rainwater in northern sites (Hanoi, Hoa Binh, Yen Bai and Cuc Phuong) (Figure 2.2). Ionic composition in rainwater of central and southern sites (Da Nang, Can Tho and Ho Chi Minh) have traced sea salt effect leading to high concentration of Cl^- and Na^+ ions, especially at Da Nang site (Figure 2.2).

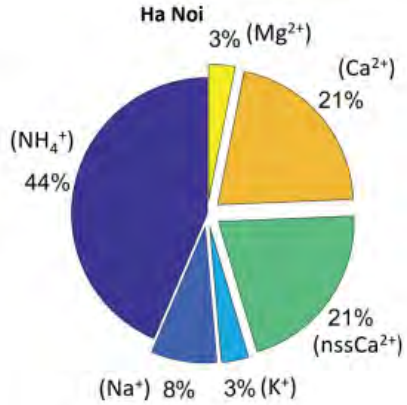

Yen Bai
(11%)
(Cl⁻)
(SO4 2-)
29%
32%
(NO3⁻)
28%
(nss-SO4 2-)

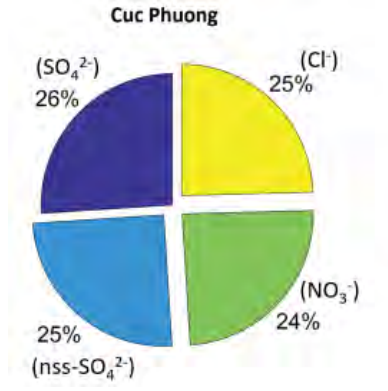

Yen Bai
3%
(Mg2+)
(Ca2+)
21%
(NH4+)
45%
21%
(nssCa2+)
(Na+)
7%
4%
(K+)

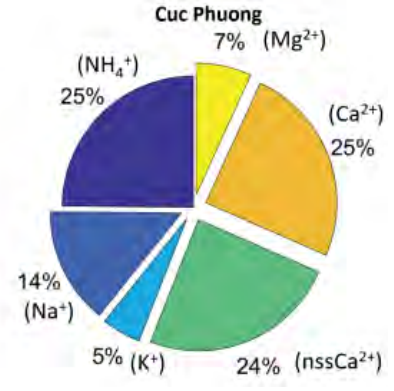

Hoa Binh
(10%)
(Cl⁻)
(SO4 2-)
30%
31%
(NO3⁻)
29%
(nss-SO4 2-)


Hoa Binh
4%
(Mg2+)
(Ca2+)
21%
(NH4+)
44%
21%
(nssCa2+)
(Na+)
7%
5%
(K+)


Ha Noi
(11%)
(Cl⁻)
(SO4 2-)
31%
28%
(NO3⁻)
30%
(nss-SO4 2-)


Ha Noi
3%
(Mg2+)
(Ca2+)
21%
(NH4+)
44%
21%
(nssCa2+)
(Na+)
8%
3%
(K+)


Cuc Phuong
(Cl⁻)
25%
(SO4 2-)
26%
(NO3⁻)
24%
25%
(nss-SO4 2-)


Cuc Phuong
7%
(Mg2+)
(NH4+)
25%
(Ca2+)
25%
14%
(Na+)
5%
(K+)
24%
(nssCa2+)

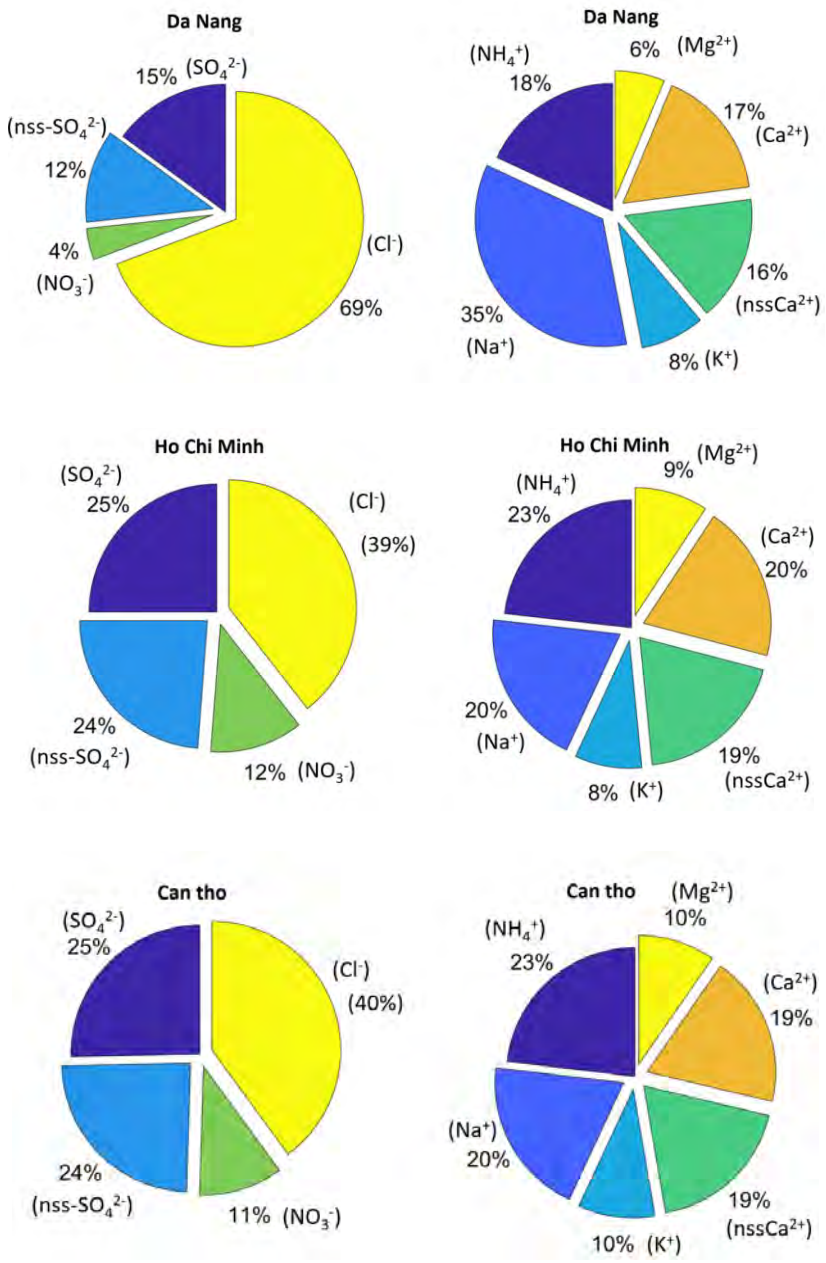


Figure 2.2. Major ion composition of rain water in sites.

c) Trend of annual ion concentration and wet deposition variation

Annual variation of nss-SO_4^{2-}, NO_3^-, H^+ ions concentration and wet deposition measured at monitoring sites between 2010 – 2019 are presented in Figures 2.3 - 2.5. During the 10-year period, in general, there was no noticeable increasing or decreasing trend in concentration and deposition of ions nss-SO_4^{2-}, NO_3^-, H^+ in rain water at most of the monitoring stations. Except, there is a clearly increasing trend in the concentration of nss-SO_4^{2-}, NO_3^- ions at Hanoi station and a decreasing trend in the concentration of NO_3^-, H^+ ions at Da Nang station. Notably, 2 urban stations Hanoi and Ho Chi Minh have a relatively high concentration of nss-SO_4^{2-}, NO_3^- ions, but the concentration of H^+ is smaller compared to other stations. Meanwhile, Cuc Phuong (remote station) and Yen Bai (rural

station) have the highest concentration of H^+ ion up to several dozens of µmol/L while the others are only few µmol/L. In general, the northern stations (Yen Bai, Hoa Binh, Ha Noi, Cuc Phuong) have higher concentrations of nss-SO_4^{2-}, NO_3^-, H^+ ions comparing with the central station (Da Nang) and the southern stations (Ho Chi Minh, Can Tho).

In addition, it was also found out that there is a clear correlation between concentration of nss-SO_4^{2-}, NO_3^-, H^+ ions and deposition at most of stations (correlation coefficiency R= 0.7-0.9) . However, the correlation between precipitation and concentration or deposition is unclear (correlation coefficiency R= 0.0-0.8). Thus, it can be inferred that the deposition level at these stations depends mainly on ion concentration and partly on precipitation. Therefore, the total annual rainfall in the northern region (in average of 2000mm/year) is lower than that in the central and southern regions (in average of 2400mm/year), but the total annual deposition of nss-SO_4^{2-}, NO_3^-, H^+ ions at northern stations (Ha noi, Yen Bai, Hoa Binh, Cuc Phuong, in average of 95mmol/m^2) are still higher than at central station (Da Nang, in average of 45mmol/m^2) and in the southern stations (Ho Chi Minh and Can Tho, in average of 85mmol/m^2) (detailed in Figure 2.3 - 2.5).

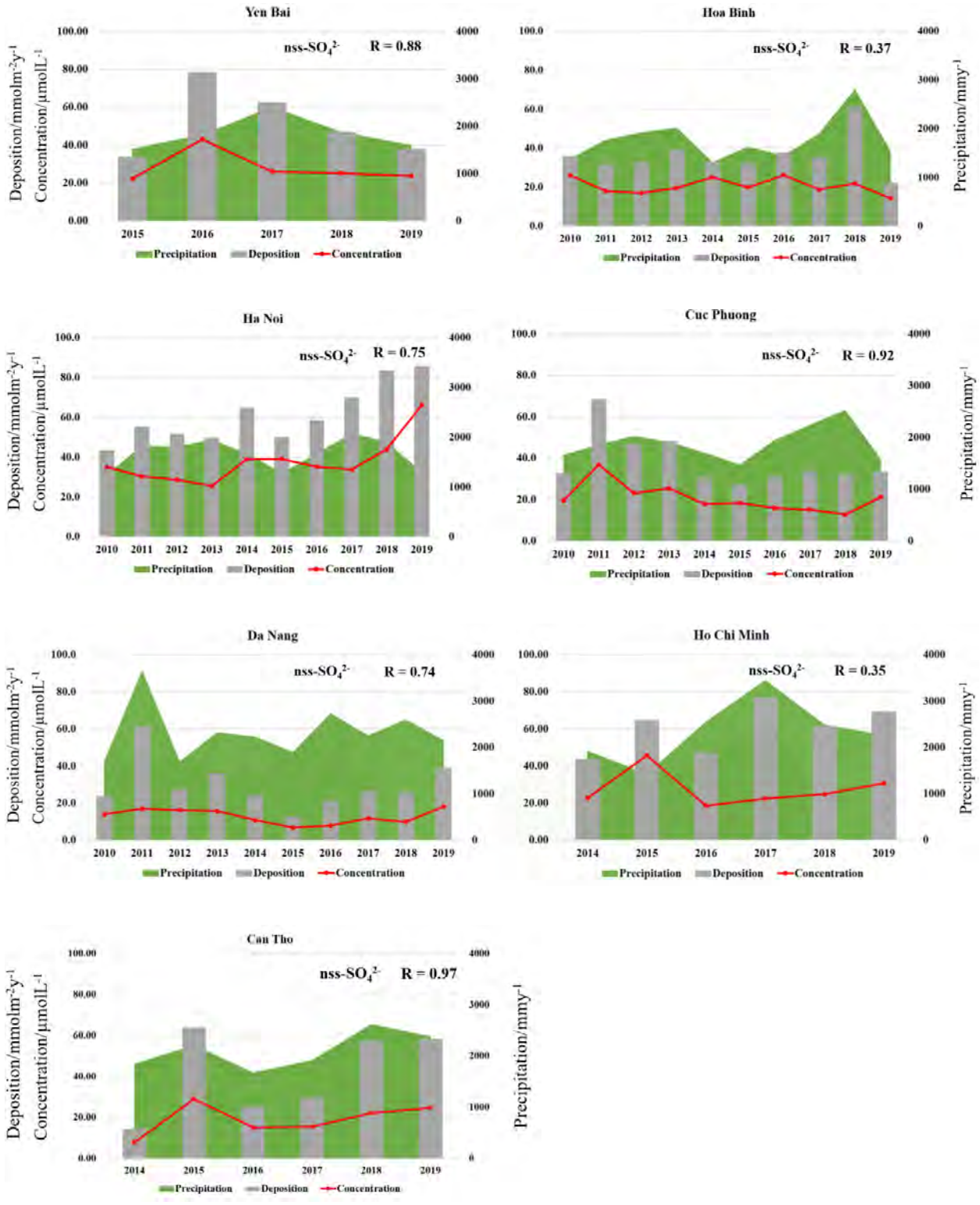


Figure 2.3. Variation of annual nss-SO_4^{2-} concentration and wet deposition in sites (2010 – 2019).

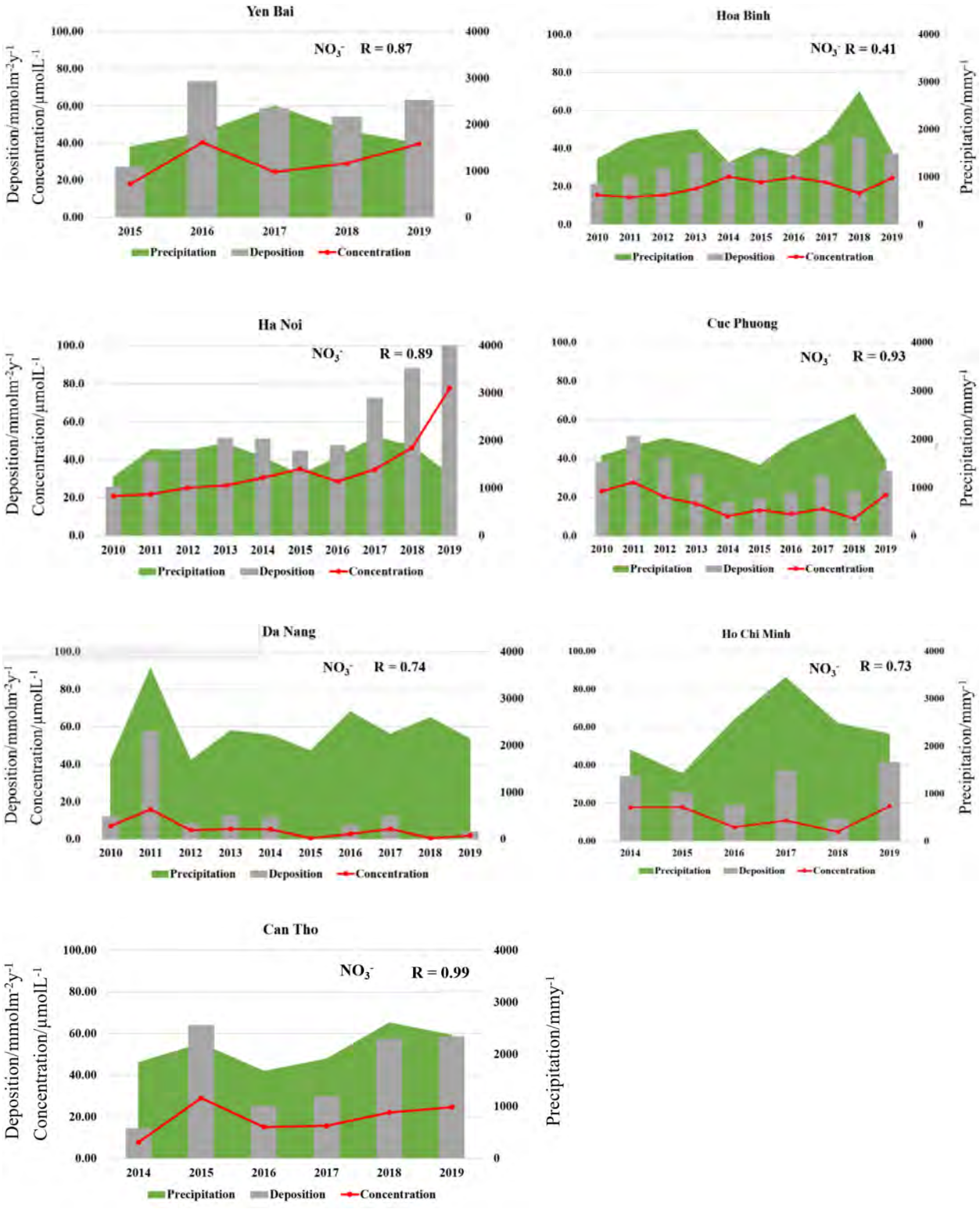


Figure 2.4. Variation of annual NO_3^- concentration and wet deposition in sites (2010 – 2019).

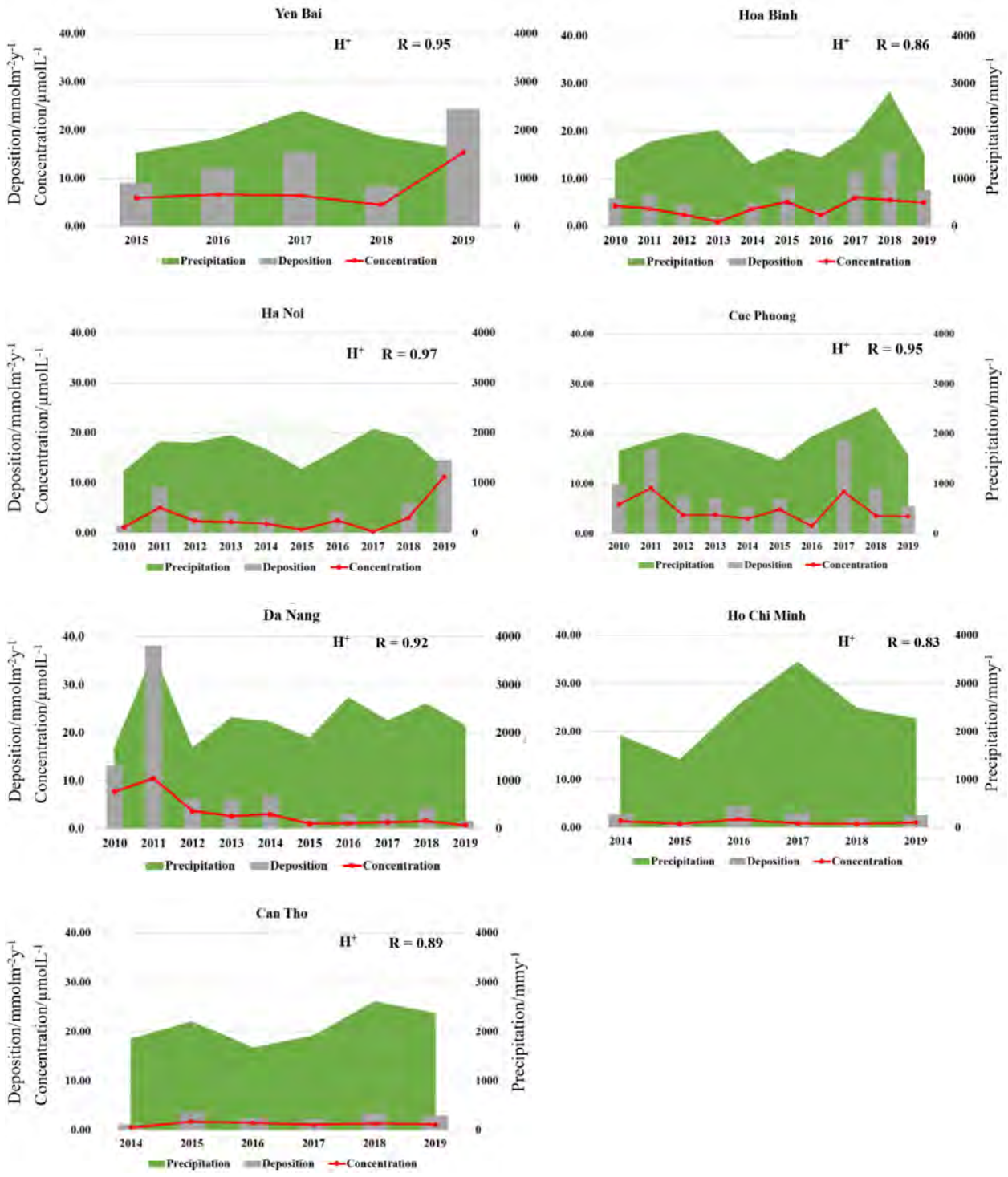


Figure 2.5. Variation of annual H^+ concentration and wet deposition in sites (2010 – 2019).

d) Seasonal variation of pH and ion concentration in sites (2010 – 2019)

In Vietnam, rainfall has been varied by seasons and by regions. Annual precipitation concentrates mainly on rainy season. Rainy season often takes place from May to September for northern region, from June to November for central region and from May to November for southern region. According to the statistical results of 10 years (2010-2019), pH often gets the lowest value in dry season, except

for Yen Bai site (see Figure 2.6). Concentration of major ions (SO_4^{2-}, NO_3^-, NH_4^+, Ca^{2+}) in rainwater often get higher values in dry season and lower in rainy season for almost sites (detailed in Figure 2.7 - 2.10). The large rainfall in rainy season had diluted ionic concentration in rainwater, leading to the concentration decreased in rainy season. However, the seasonal variation pattern is very typical for northern sites (Hanoi, Hoa Binh, Cuc Phuong, Yen Bai) but little unclear for central site (Da Nang) and southern sites (Ho Chi Minh and Can Tho).

In case of Yen Bai site, its pH values in rainy season are lower than those in dry season, while its concentration of 2 acid precursors (nss-SO_4^{2-}, NO_3^-) in rainy season are lower. It is necessary to do further study for cause.

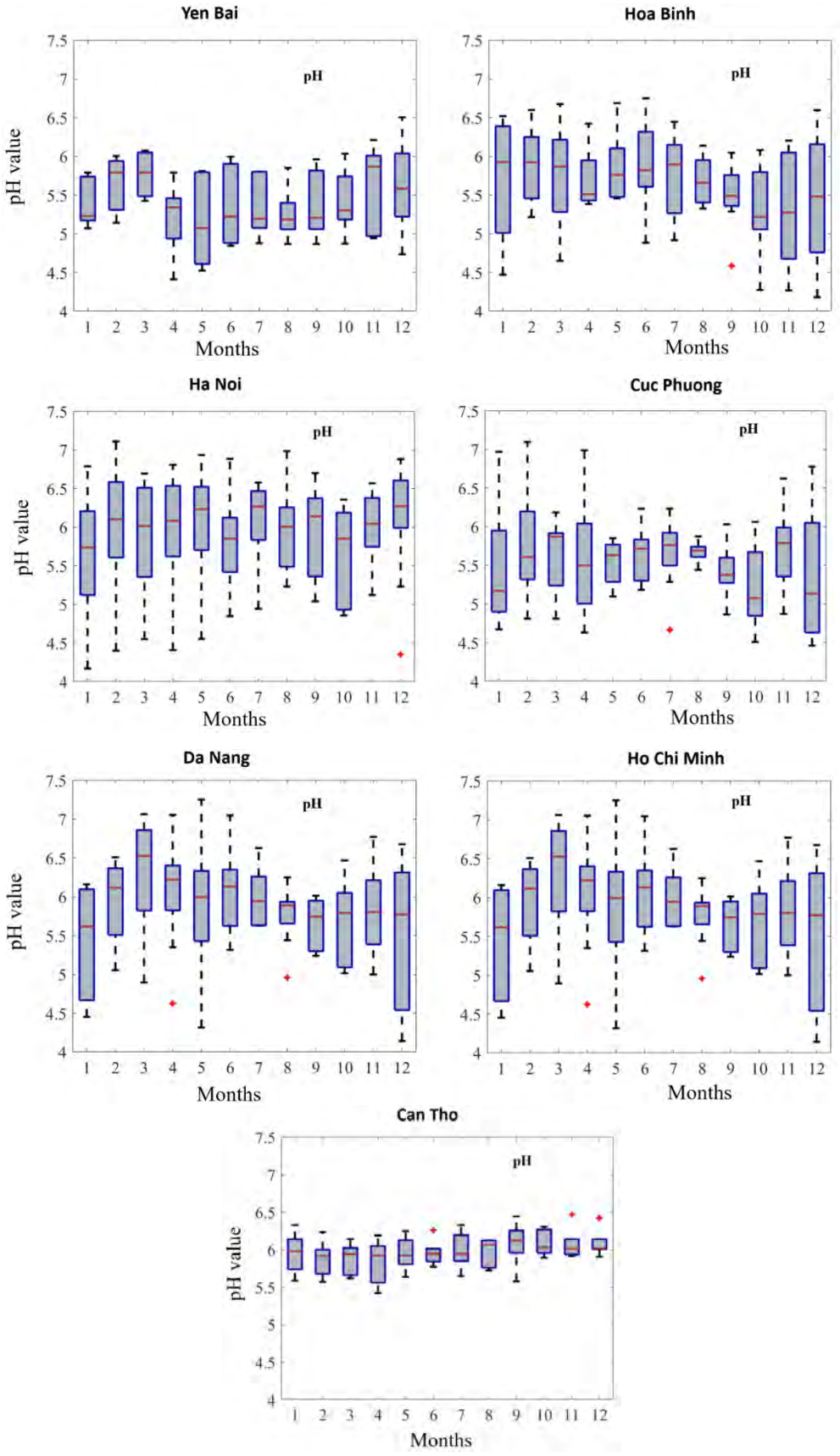


Figure 2.6. Seasonal variation of rain water pH values in sites.

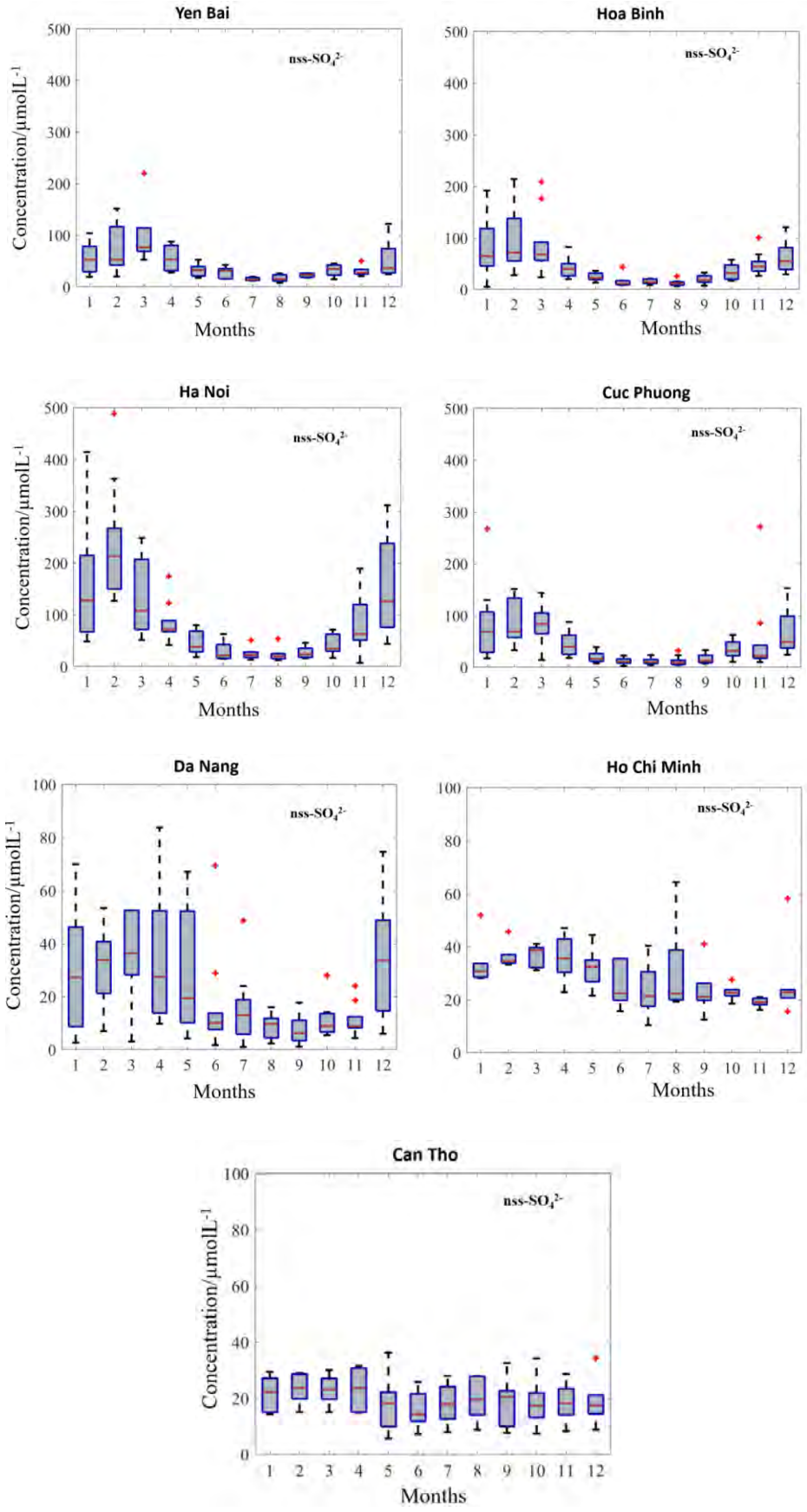


Figure 2.7. Seasonal variation of nss-SO_4^2 ion deposition in sites (2010 – 2019).

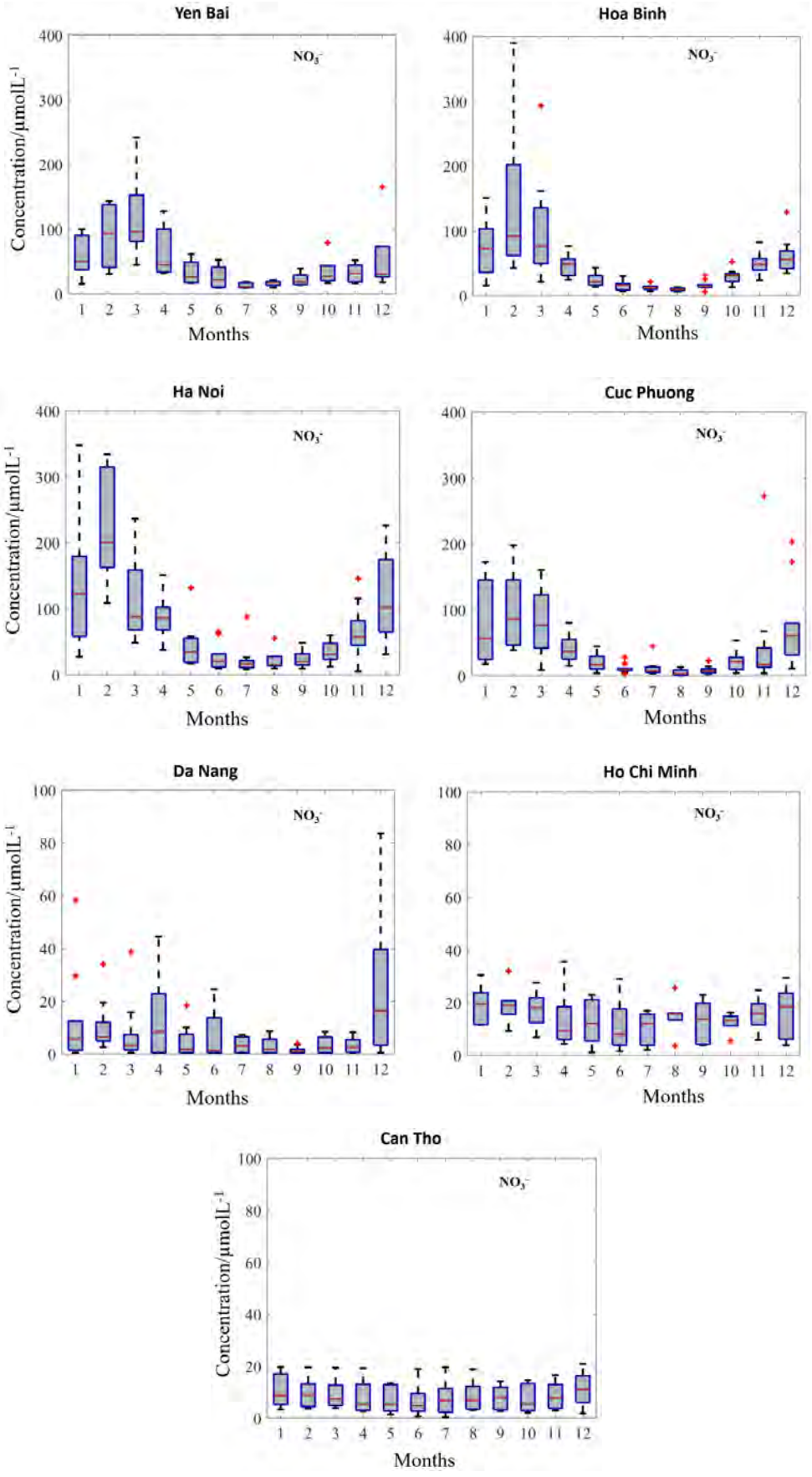


Figure 2.8. Seasonal variation of NO_3^- ion deposition in sites (2010 – 2019).

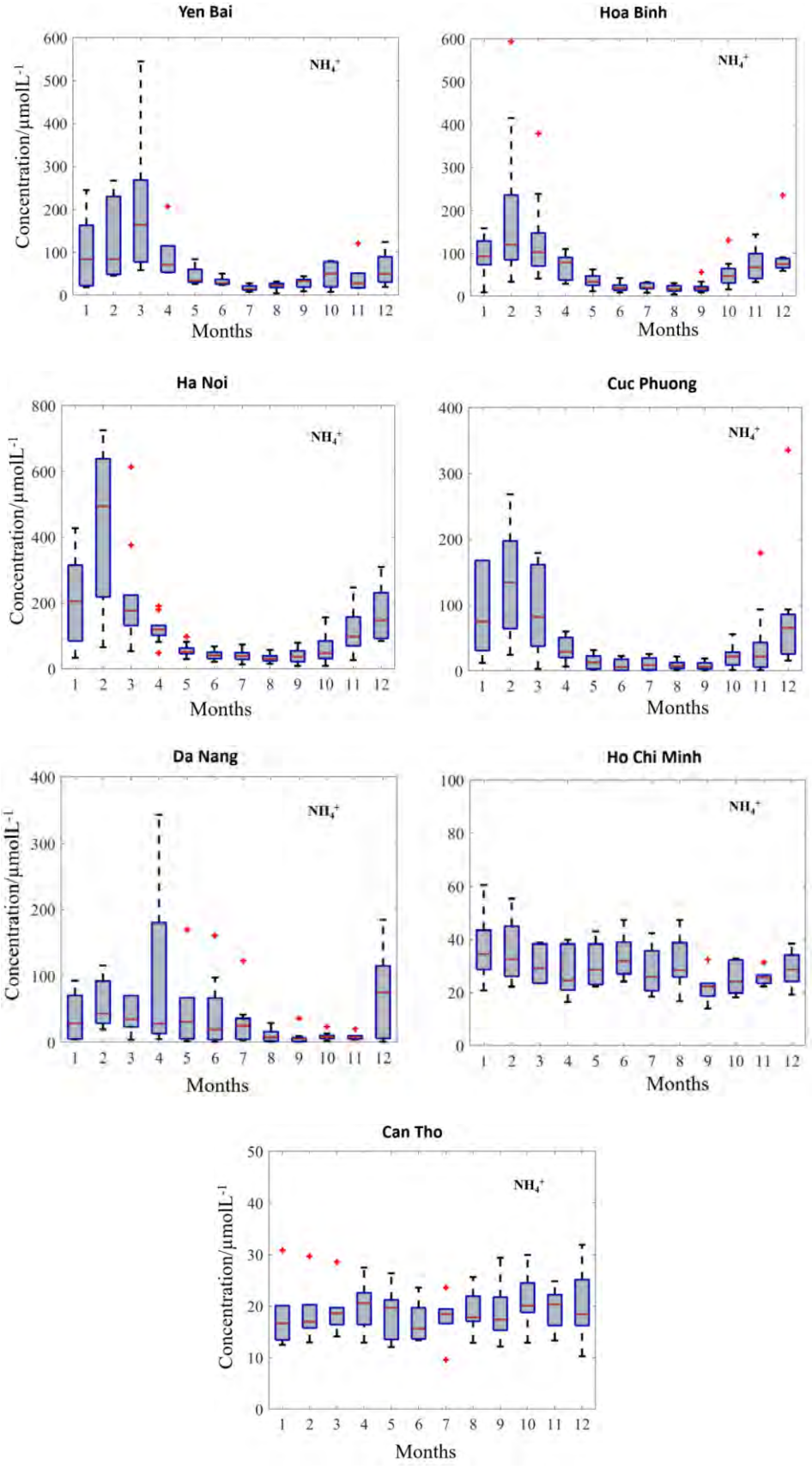


Figure 2.9. Seasonal variation of NH_4^+ ion concentration in sites.

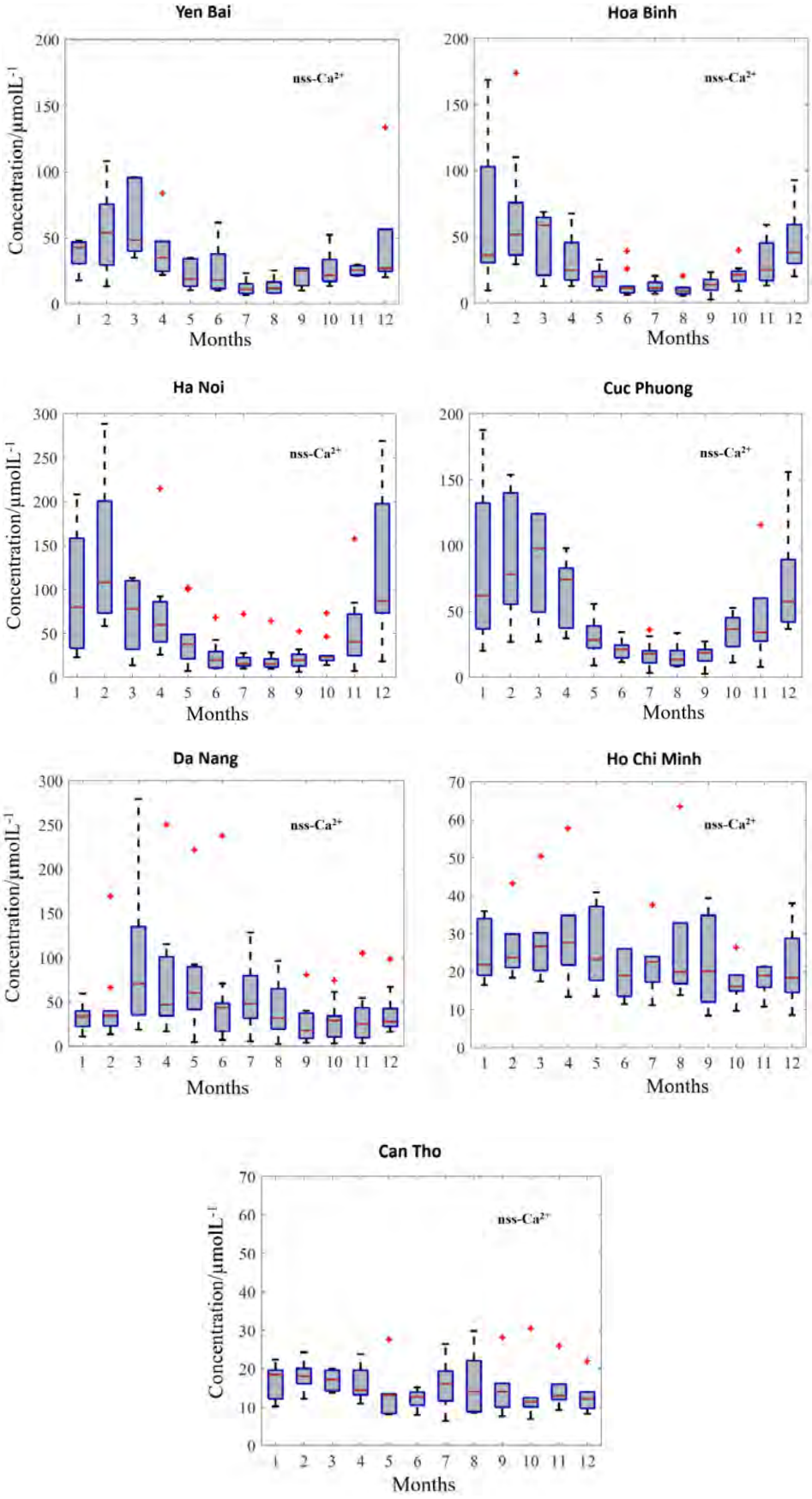
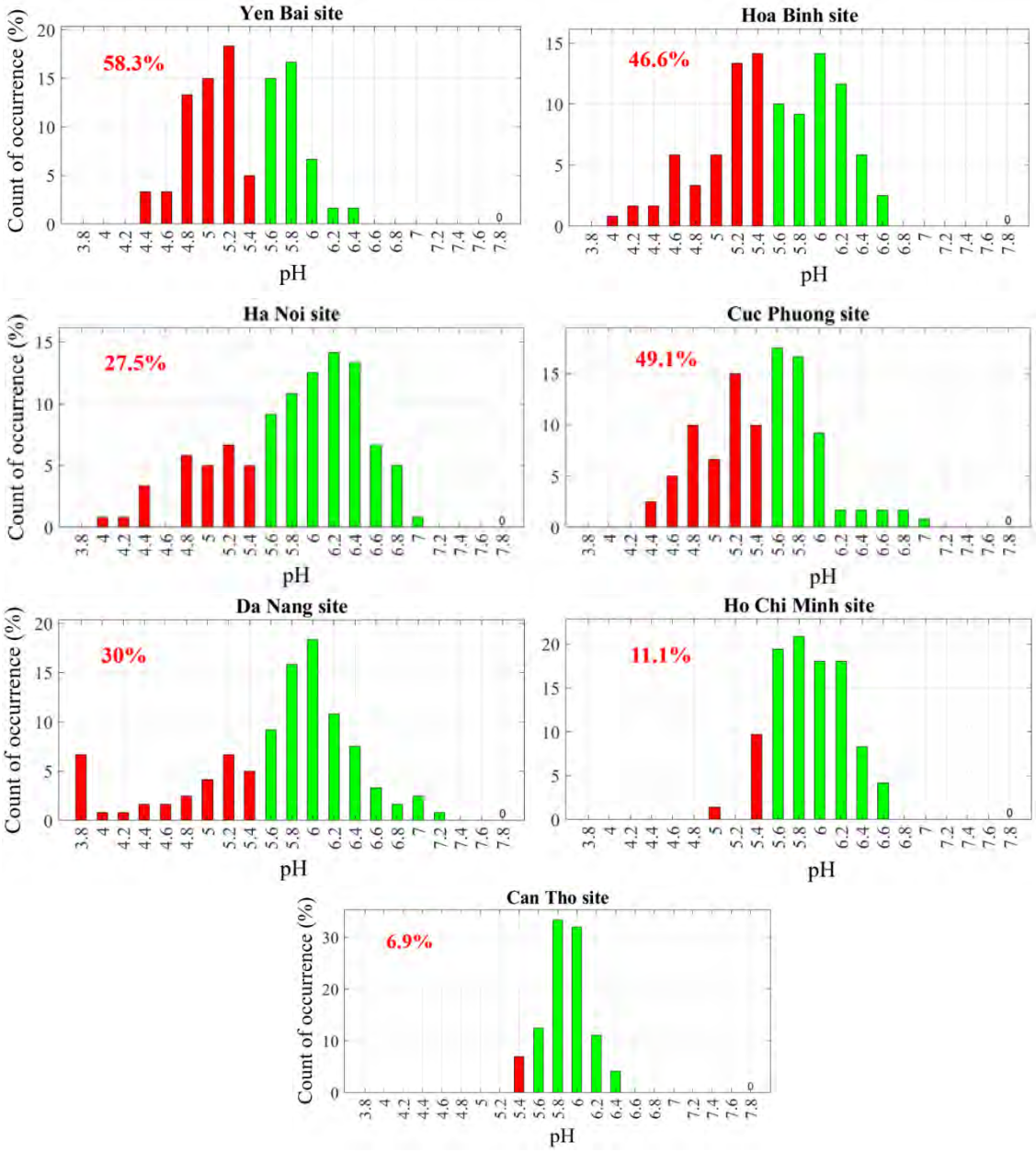


Figure 2.10. Seasonal variation of nss-Ca^{2+} ion concentration in sites (2010 – 2019).

e) Current state of acid rain

Result on assessing current state of acid rain (pH<5.6) in period of 2010- 2019 shows that acid rain had occurred for all of 7 Vietnam's EANET sites with frequency varies from site to site. The highest acid rain frequency is observed at Yen Bai site (58.3%), followed by Cuc Phuong site (49.1%), next to Hoa Binh site (46.6%) and Da Nang site (30%), Hanoi site (27.5%), Ho Chi Minh (11.1%). Can Tho site has the lowest acid rain frequency of 6.7%. It can be realized that acid rain frequency of northern and central sites (Yen Bai, Hoa Binh, Cuc Phuong, Ha Noi, Da Nang) is higher than southern sites's (Ho Chi Minh, Can Tho). Specially, acid rain had occurred with the highest frequency in remote (Cuc Phuong) and rural sites (Yen Bai, Hoa Binh) but not in urban sites (Ha Noi, Da Nang, Ho Chi Minh) (Figure 2.11).



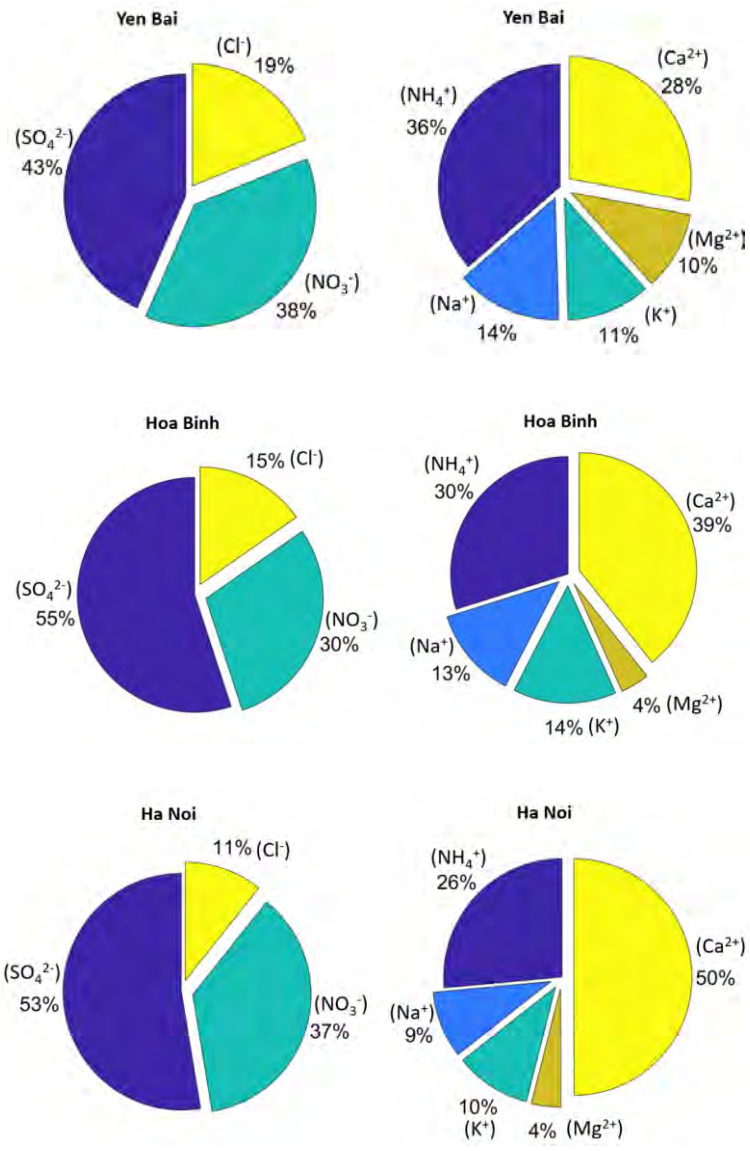
Note: For Ho Chi Minh site and Can Tho site, pH data are collected from 2014. For Yen Bai site, pH data are collected from 2016.

Figure 2.11. Frequency distribution of rainwater pH values in sites (2010 – 2019).

2.2 State of dry deposition

a) Gases and aerosol concentration and composition

Filter pack sampling technique is employed at all of 5 EANET sites (Yen Bai, Hoa Binh, Hanoi, Ho Chi Minh and Can Tho) in Vietnam. Measured results show that. for all of sites, ionic concentrations of Ca^{2+}, NH_4^+ and SO_4^{2-}, NO_3^- are dominant (63-76% and 78-90%, respectively) in aerosol composition (Figure 2.12).



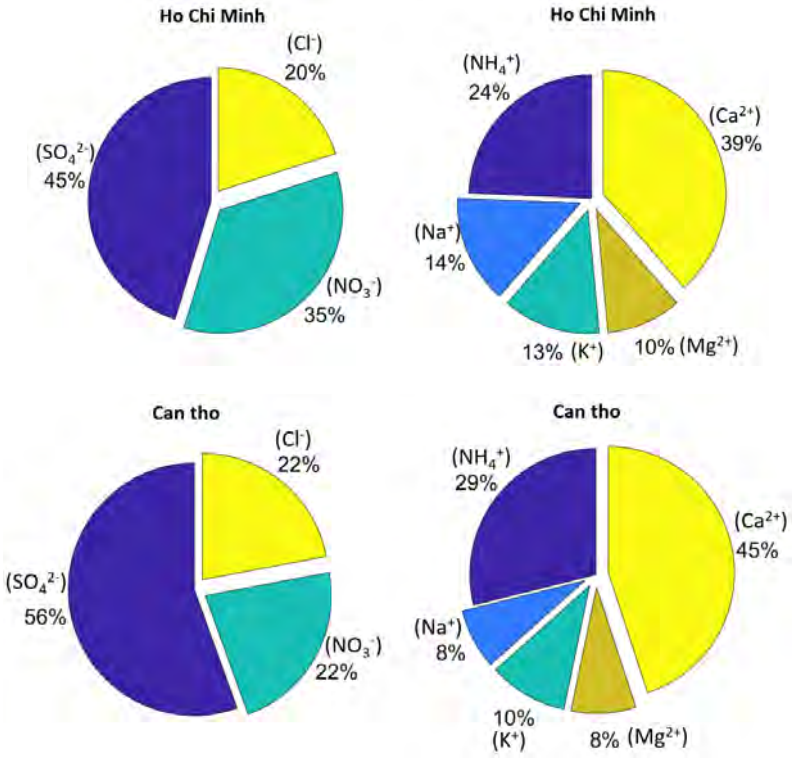


Figure 2.12. Major ion composition of aerosols in sites.

During 2010- 2016, annual SO_2 concentration in Hanoi and Hoa Binh are always higher than others, however, they have had a significantly decreasing trend for recent years. In addition, seasonal variation (increasing in dry season and decreasing in rain season) is also observed for Hanoi, Hoa Binh and Ho chi Minh sites. Especially, it seems that there is a reversed pattern for Yen Bai sites (decreasing in dry season and increasing in rain season).

For annual HNO_3 and NH_3 concentrations, Hanoi and Ho Chi Minh (2 urban sites) and Yen Bai (rural site) are generally higher than others. However, it is recognized that a dramatically increasing trend of NH_3 concentration has happened in Can Tho site for recent years (Figure 2.13).

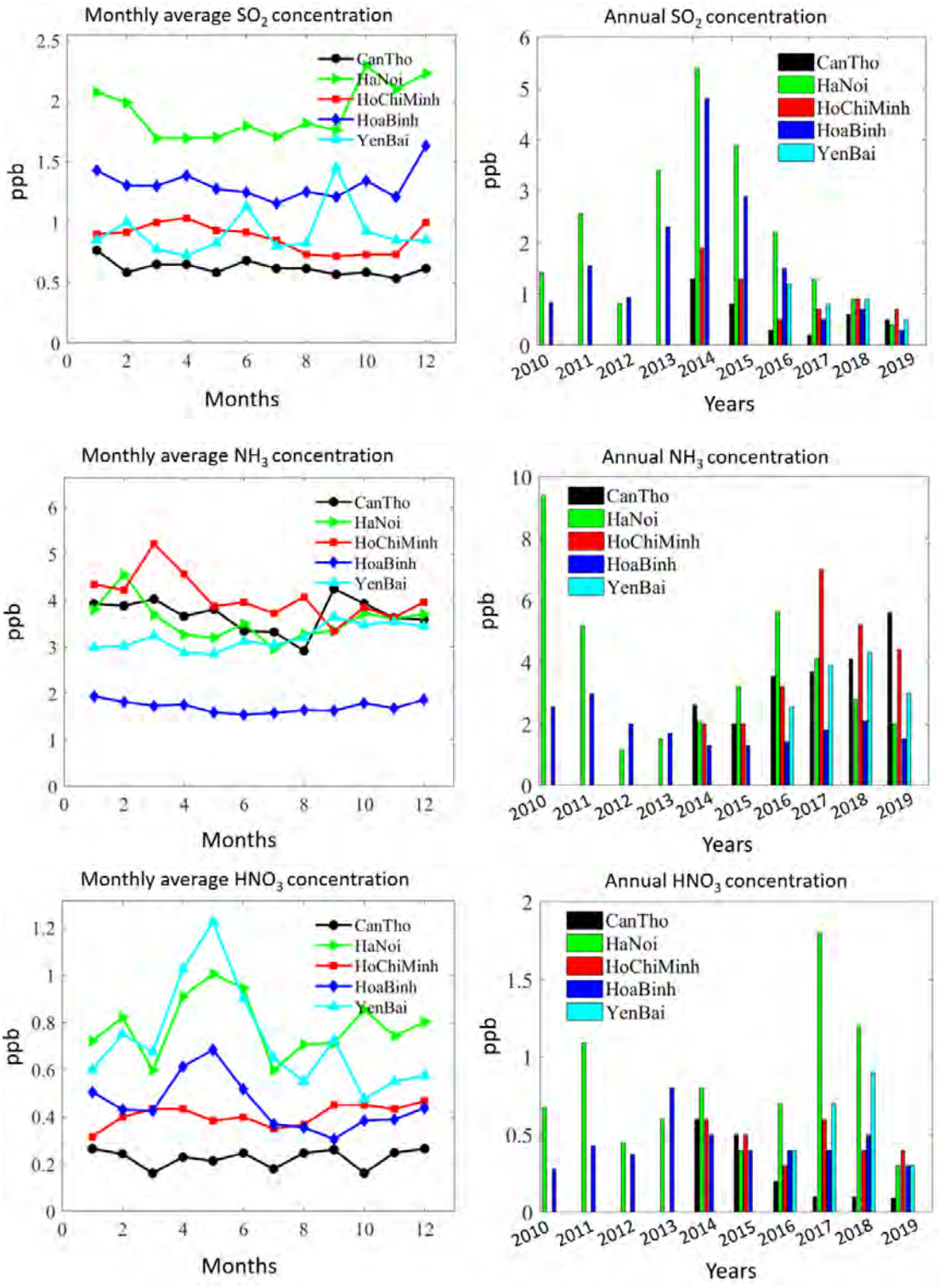


Figure 2.13. Variation of gases concentration in sites (2010-2019).

2.3 State of inland aquatic environment

Since 2001, Hoa Binh reservoir has been selected to monitor acid deposition for inland aquatic environment in Vietnam. Inland water samples are taken quarterly/seasonally (every March/ spring,

June/ summer, September/ autumn and December/ winter). Results of ionic concentration analysis showed that HCO_3^- and Ca^{2+} are predominant in ionic composition of Hoa Binh reservoir water.

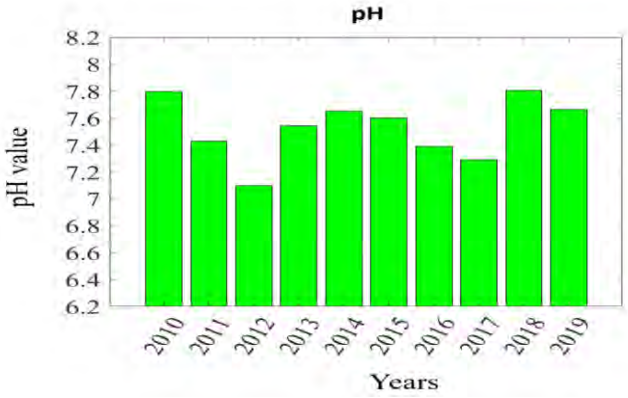


Figure 2.14. Variation of annual average pH values in Hoa Binh reservoir water.

In period of 2010- 2019, annual average pH values are fluctuated in range of 7.1 - 7.8, so Hoa Binh reservoir is not acidified (Figure 2.14). Seasonal variation of pH values is not detected. But seasonal variation is observed for EC and major ions concentration. In detail, EC values and SO_4^{2-}, Mg^{2+} concentration get higher values in spring (March) and summer (June) while NO_3^- and Ca^{2+}concentration get the highest in winter (December) and the lowest in summer (June) (Figure 2.15 – 2.17).

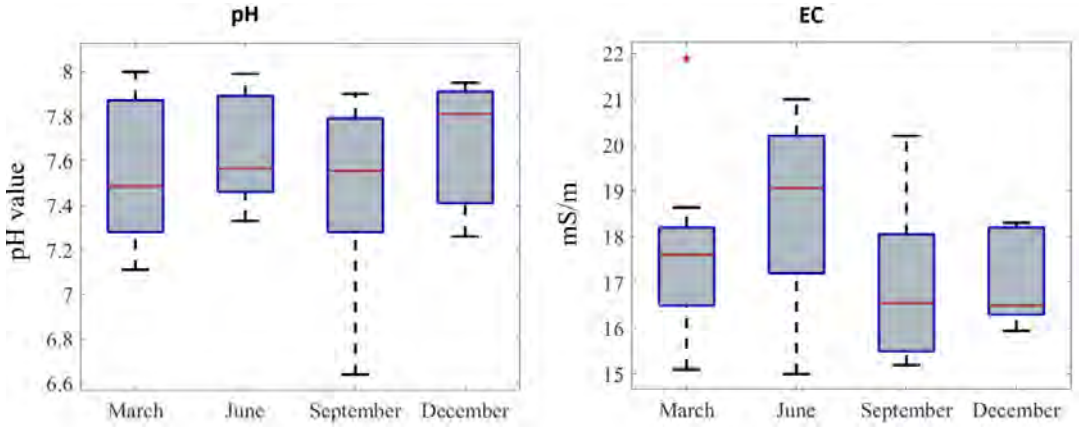


Figure 2.15. Seasonal variation of pH and EC values in Hoa Binh reservoir water (2010-2019).

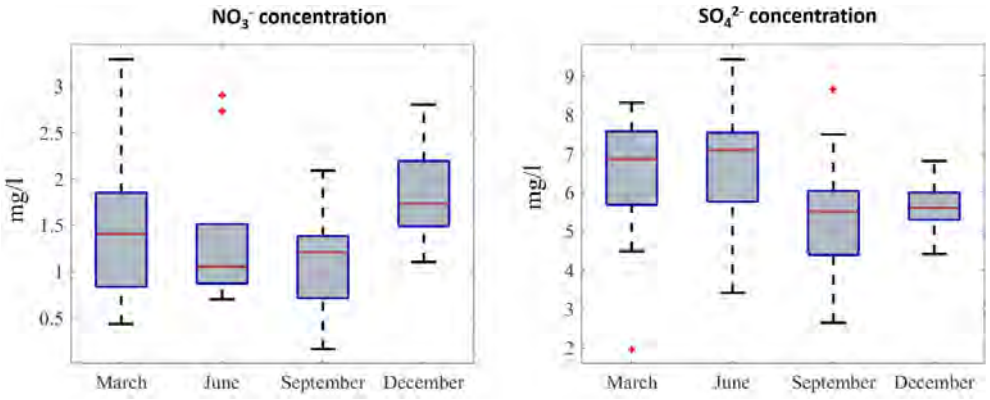


Figure 2.16. Seasonal variation of NO_3^- and SO_4^{2-} concentration in Hoa Binh reservoir water (2010-2019).

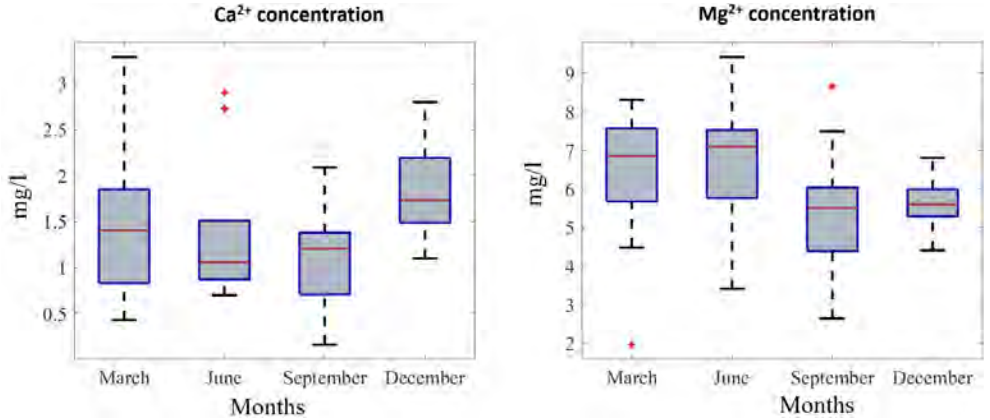


Figure 2.17. Seasonal variation of Ca^{2+} and Mg^{2+} concentration in Hoa Binh reservoir water (2010-2019).

As Hoa Binh reservoir has a high alkalinity (1500 µeq/l), so it is not sensitive to acid deposition. Therefore, further studies are needed to detect changes in lake water composition over the past 20 years.

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URL: http://www.eanet.asia

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