Periodic Report on the State of Atmospheric Environment in EANET China

(PRSAE5, China, 2000-2024)

China National Environmental Monitoring Center (CNEMC)

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Thank you for the great support from the 6 participating cities' monitoring centers, which are Chongqing Ecological and Environmental Monitoring Center, Xi'an Environmental Monitoring Center Station, Guangdong Zhuhai Environmental Monitoring Center Station, Fujian Xiamen Environmental Monitoring Center Station, Wuzhishan City Ecological Environment Protection Monitoring Station and The Ecological and Environmental Monitoring Station of DEEY in Lijiang.

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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 regional monitoring network dedicated to monitoring and assessing the status and environmental impacts of acid deposition across East Asia. As an official member of EANET, China has conducted long-term continuous acid deposition monitoring in accordance with unified requirements since the official launch of EANET in 2001.

Four participating cities namely Chongqing, Xiamen, Xi'an and Zhuhai have implemented synchronous monitoring of wet deposition, dry deposition, inland water, soil and vegetation starting from 2001. In 2019, two additional cities, Wuzhishan and Lijiang, were formally incorporated into the EANET monitoring network, undertaking wet and dry deposition monitoring tasks respectively. As the national monitoring center of EANET in China, China National Environmental Monitoring Center (CNEMC) develops annual national monitoring plans in line with EANET technical guidelines, organizes and oversees all domestic EANET-related monitoring activities, and verifies and audits monitoring data submitted by the six above-mentioned monitoring cities.

1.2 Monitoring Sites

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, including 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 2001-2024, 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 km 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. To ensure the continuity of EANET's monitoring, a new precipitation monitoring site, Haifu monitoring site (106°30' E , 29°37' N , 317 meters by altitude) was selected, and it was 6 km 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 km 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 2001-2024, 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 site of Weishuiyuan 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 km 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℃ and 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 2001-2024, 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 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. It has a longitude of 118°08' E, latitude of 24°28' N and altitude of 50 meters. 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 situated deep within the remote forested area of Xiamen, far from highways, railways, urban zones and anthropogenic-activity sources. Its geographic coordinates are 118° 2′ E, 24° 51′ N, with an elevation of 686 m

1.2.4 Zhuhai:

Two sites of Xiangzhou (urban site) and Zhuxiandong (urban site) in Zhuhai City carried out acid deposition monitoring.

Xiangzhou: The monitoring site is on the roof of the building of Zhuhai Environmental Monitoring Center in downtown Zhuhai. It has a longitude of 113°34’ E, latitude of 22°16' N and altitude of 40 meters. 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.

Haibin-park: The Haibin Park site is a urban site, relocated from the former Xiangzhou station at Haibin North Road to Haibin Park at Xiangzhou District, Xiangluwan Bay in 2012. This site is located in the coastal urban area affected by urban traffic, commerce and residential emissions. It conducts continuous automatic monitoring for dry deposition parameters.

Zhuxiandong: This site is located in Zhuxiandong scenic tourist area of Nanping Township, about 15 km from the city. It has a longitude of 113°31’ E, latitude of 22°12’ N and altitude of 45 meters. It borders Lizhi Mountain in the south and Nanwan Road in the north. Multiple acid deposition-related monitoring activities are currently conducted at the Zhuxiandong site, including wet deposition, soil and vegetation surveys, and inland water monitoring.

1.2.5 Wuzhishan and Lijiang:

Wuzhishan： Wuzhishan is a city of Hainan Province, which is located in the south of China. It has a longitude of 109°30’E, latitude of 18°50’N and altitude of 958 meters. This site is an atmospheric background station.

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

Both sites are remote sites that officially joined EANET in 2019. They are highly representative: located in areas with low population density, excellent natural ecological conditions, and distant from urban and anthropogenic pollution sources, they can authentically reflect regional ambient air quality and acid rain background conditions. The monitoring programs implemented at these two sites include 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

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.

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, 9:00-9:00
Dry deposition	SO_2, NO_2, PM_{10}, $PM_{2.5}$,O_3	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 5 years
Vegetation	description of trees, understory vegetation survey	Every 3-5 years
	observation of tree decline	Every year

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 EANET cities in China has selected one site for dry deposition monitoring, with an hourly frequency covering sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and inhalable particulate

matter (PM_{10}) in the air. According to the supplementary document of the instrument, three cities including Zhuhai, Xiamen and Chongqing, have submitted $PM_{2.5}$ and ozone (O_3) monitoring data to the network starting November 2022.

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, colour, transparency, COD, NO_2^- and PO_4^{3-} are suggested to be monitored once a year.

1.3.4 Soil and vegetation monitoring

Four EANET-participating cities in China (Xi'an, Zhuhai, Xiamen and Chongqing) have carried out soil and vegetation monitoring. Vegetation surveys are conducted once per year, and soil monitoring is conducted every five years.

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 includes tree characterization, understory vegetation surveys, tree health decline observations, and other related items.

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, 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 (2024)

City name	Monitoring site	Sampling method	Sampler information
Chongqing	Jinyunshan	auto	UNS130/E (Eigenbrodt)
	Haifu	auto	US-320H (Ogasawara)
Xi'an	Shizhan	auto	DSSI (Xuanhui, Qingdao)
	Jiwozi	auto	XHARS30A (Hebei Sailhero)
Xiamen	Hongwen	auto	ASP-3A(Xianglan, Changsha)
	Xiaoping	auto	ASP-3A(Xianglan, Changsha)
Zhuhai	Xiangzhou	auto	ZJC-V (Hengda, Hangzhou)
	Zhuxiandong	auto	ZJC-III (Hengda, Hangzhou)
Wuzhishan	Wuzhishan	auto	LAOYING 5020 (Laoying, Qingdao)
Lijiang	Lijiang	auto	ZR-3901 (Zhongrui, Qingdao)

1.4.2 Sample analysis

Detailed sample information shall be recorded on-site and subsequently provided to laboratory analysts. Samples are filtered using a 0.45 μm membrane filter prior to ion analysis, and the ion analysis shall be finished within one week after sampling.

Table 5 Measurement method, instrument information of the laboratory

City name	Monitoring parameters	Measurement method	Instrument information
Chongqing	pH	Glass electrode method	METTLER TOLEDO S210
	EC	electrode method	CM-60G
	F^-, Cl^-, NO_3^-, SO_4^{2-},Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}	IC	DIONEX-Integrion HPIC
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	Thermo Scientific ICS-5000
Xiamen	pH	Glass electrode method	Mettler Toledo
	EC	electrode method	Mettler Toledo
	NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} Cl^-, NO_3^-, SO_4^{2-}	IC	Thermo Scientific ICS-5000
Zhuhai	pH	Glass electrode method	SevenExcellence S470-B （METTLER）
	EC	electrode method	Rex Electric
	NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} Cl^-, NO_3^-, SO_4^{2-}	IC	DIONEX-ICS-6000
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	Thermo Scientific 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	Thermo Scientific ICS-1100

1.4.3 QA/QC of wet deposition monitoring

In line with EANET's quality assurance and quality control (QA/QC) requirements for wet deposition monitoring, all six Chinese participating units of EANET comply strictly with relevant standards across all stages of monitoring activities. Since 2001, analytical laboratories from four cities, Chongqing, Xi'an, Zhuhai and Xiamen, have taken part in EANET's annual interlaboratory comparison programs covering wet deposition, dry deposition, soil and inland water. Wuzhishan and Lijiang monitoring sites joined these interlaboratory comparisons starting in 2019, and all participating laboratories have consistently obtained satisfactory test results.

Figure 1 illustrates the annual proportions of wet deposition samples that individually satisfy the quality criteria of ion balance parameter (R1, blue line) and electrical conductivity check parameter (R2, red line) for EANET China from 2001 to 2024. R2 consistently outperformed R1 across the whole period. Both parameters reached minimum values in 2002 and generally improved up to 2009. During 2010-2020, R2 remained at a relatively high level with moderate fluctuations, while R1 declined substantially. Starting in 2021, R1 rebounded sharply, and both indicators maintained high qualified percentages up to 2024. The ion balance check (R1) was identified as the main limiting factor for overall wet-deposition data quality.

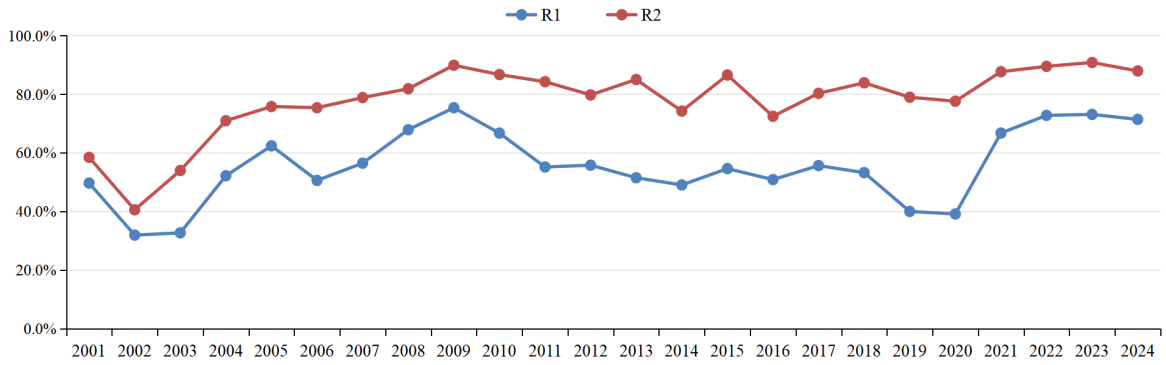


Figure 1. The Average of R_1 and R_2 in EANET China from 2001 to 2024.

Figure 2 presents the annual proportion of wet deposition samples that meet the EANET data-quality criteria for both the ion balance parameter (R_1) and electrical conductivity check parameter (R_2) across China from 2001 to 2024. The combined qualified-sample percentage dipped to the minimum around 2002, rose progressively to the first peak in 2009, then fluctuated within the range of approximately 43 %-53 % during 2011-2018, followed by a decline down to about 37 % in 2020. A sharp rebound occurred in 2021, the proportion stayed at high levels in 2021-2023 and experienced a slight fall in 2024. Higher values indicate better overall quality of wet deposition chemical measurements.

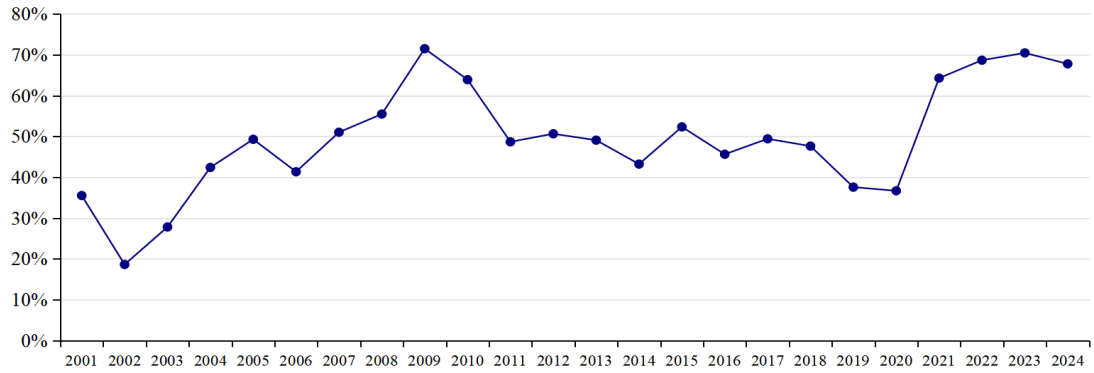


Figure 2. The Annual Average Percentage of Samples Satisfying Both R1 and R2 in EANET China from 2001 to 2024.

Chapter 2 Status Quo of Acid Deposition in EANET China

2.1 Atmospheric deposition

2.1.1 Wet deposition of EANET China

2.1.1.1 EC and pH of wet deposition in EANET China

Annual average pH values at all 10 wet deposition monitoring sites across six cities from 2000 to 2024 are presented in Figures 3–7 (data for Wuzhishan and Lijiang are available only for 2019–2024). The annual average pH for EANET China during 2000–2024 ranged from 3.94 to 7.13. The lowest annual average pH of 3.94 was recorded at the Jinyunshan site in 2010, and the highest value of 7.13 was recorded at the Shizhan site in 2022.

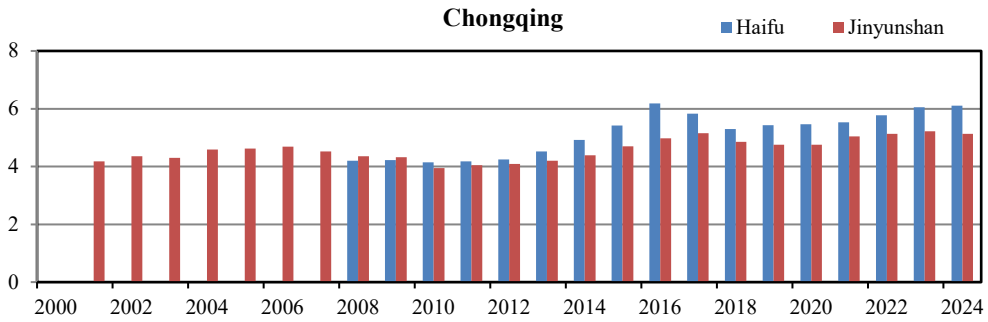


Figure 3. Annual average pH of Chongqing in 2000-2024.

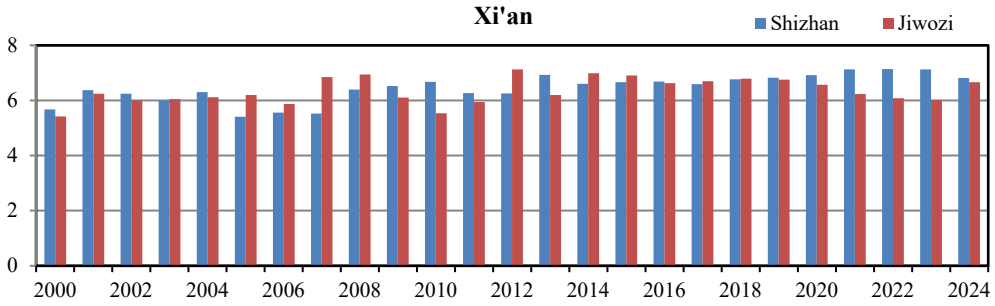


Figure 4. Annual average pH of Xi'an in 2000-2024.

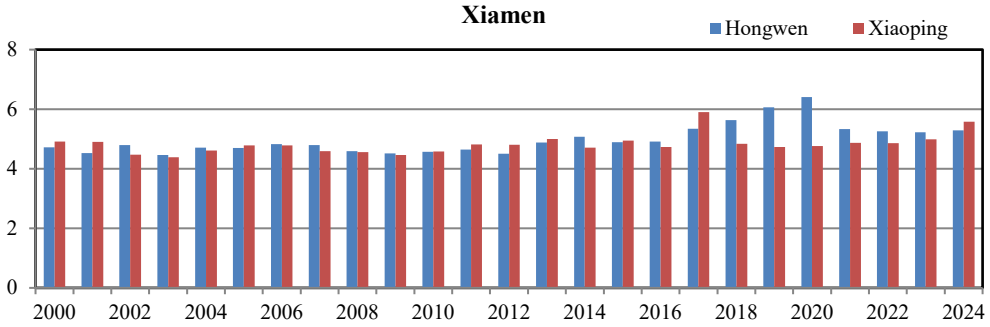


Figure 5. Annual average pH of Xiamen in 2000-2024.

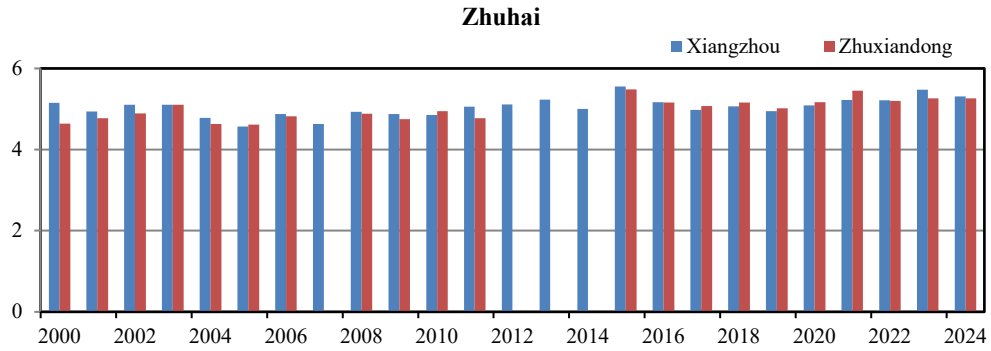


Figure 6. Annual average pH of Zhuhai in 2000-2024.

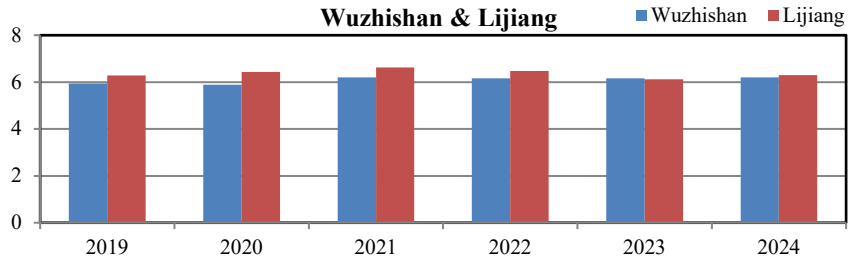


Figure 7. Annual average pH of Wuzhishan & Lijiang cities in 2019-2024.

Based on annual average pH data, Xi'an in northwest China exhibited higher annual average pH values than all other EANET China cities. Prior to 2010, Chongqing in southwest China recorded the lowest annual average pH, yet its annual average pH increased markedly after 2010. Xiamen and Zhuhai, both located along the southeast coastal region of China, maintained comparable pH levels throughout the monitoring period. Wuzhishan and Lijiang joined the EANET network in 2019, and their annual average pH values fell within the mid-range among all Chinese EANET cities. For most years, rural and remote monitoring sites across all cities yielded lower annual average pH values than urban sites.

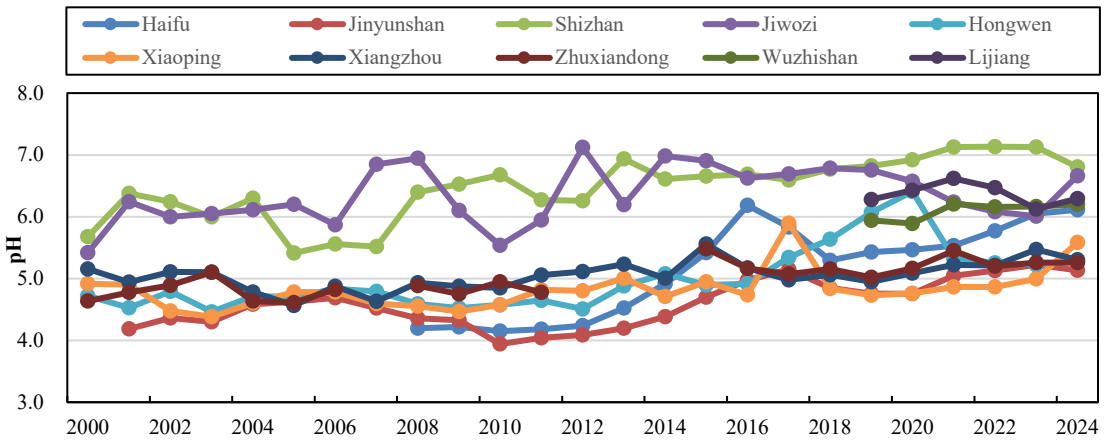


Figure 8. Trends of annual average pH of all monitoring sites, EANET China in 2000-2024.

Over the 25-year period from 2000 to 2024, the annual average precipitation pH values at China's EANET monitoring sites exhibited a slight increasing trend (Figure 8), with a more pronounced upward tendency observed between 2010 and 2024. Since 2017, pH conditions across most monitoring stations have remained relatively stable, indicating an overall improvement and steady state of precipitation acidity in recent years.

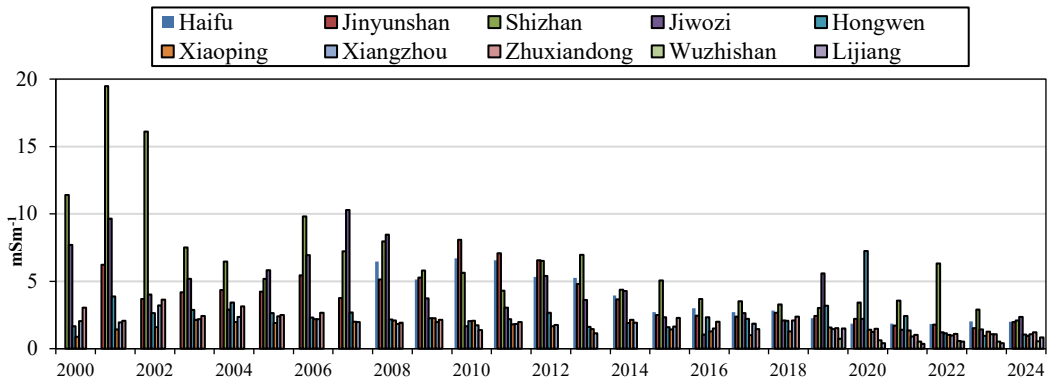


Figure 9. Annual average EC of all monitoring sites, EANET China, in 2000-2024.

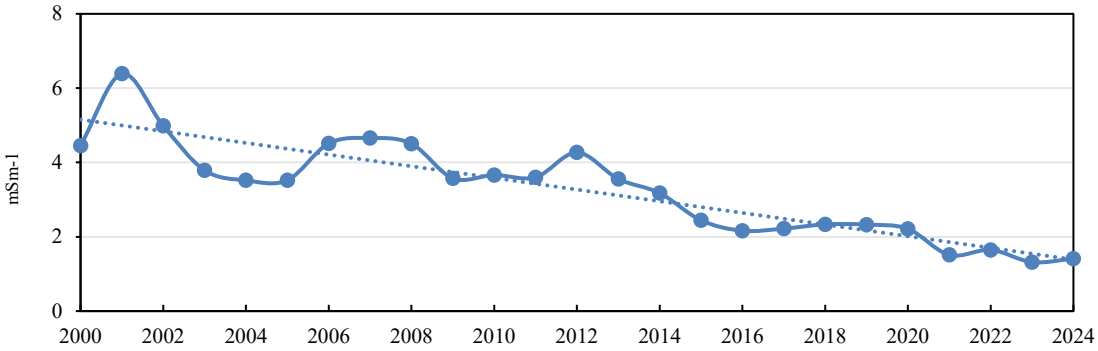


Figure 10. Trends of annual average EC of overall EANET China in 2000-2024.

In terms of precipitation electrical conductivity (EC), Figure 9 illustrates the long-term variations in annual average EC values at all Chinese EANET sites during 2000–2024. Spatially, Chongqing and Xi'an consistently maintained higher EC levels compared with Xiamen, Zhuhai, Wuzhishan and Lijiang. Such regional differences were particularly prominent from 2000 to 2014. However, EC concentrations in Chongqing and Xi'an have decreased substantially since 2014, gradually narrowing the gaps and converging toward the lower EC levels observed at other monitoring sites.

2.1.1.2 Concentrations of major ions of wet deposition of EANET China in 2000-2024

Figure 11 to Figure 13 illustrate the annual average concentrations of sulfate (SO_4^{2-}), nitrate (NO_3^-), and chloride (Cl^-) ions in wet deposition at China's EANET monitoring sites over the 2000–2024 period. Spatially, inland cities including Chongqing and Xi'an exhibited significantly higher SO_4^{2-} and NO_3^- concentrations than the southern coastal sites of Xiamen and Zhuhai. By contrast, Cl^- levels in inland areas were generally lower than those in coastal regions throughout most years, which is primarily attributable to the influence of sea salt particles on coastal wet deposition. In addition, across the entire monitoring network, rural and remote sites consistently maintained lower ionic concentrations than urban sites for all three ions over the long-term observation period.

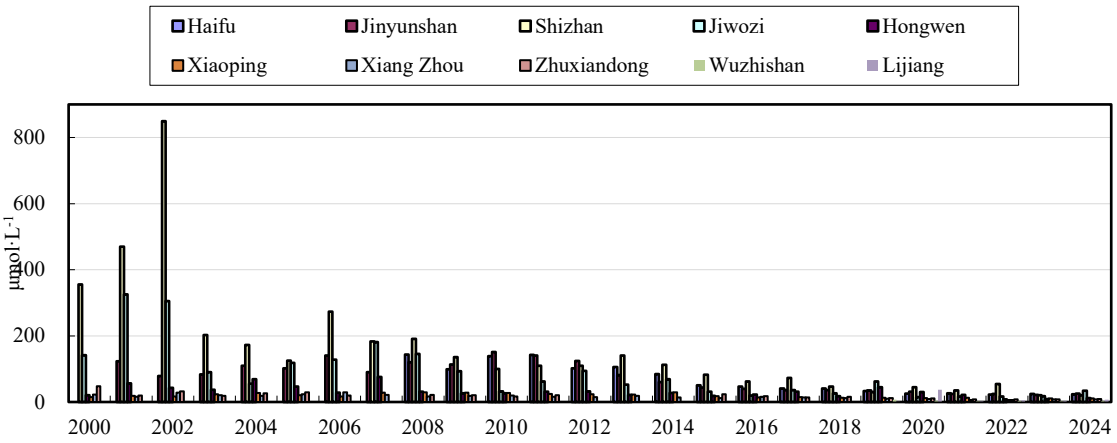


Figure 11. Annual average of SO_4^{2-} concentration of all monitoring sites, EANET China.

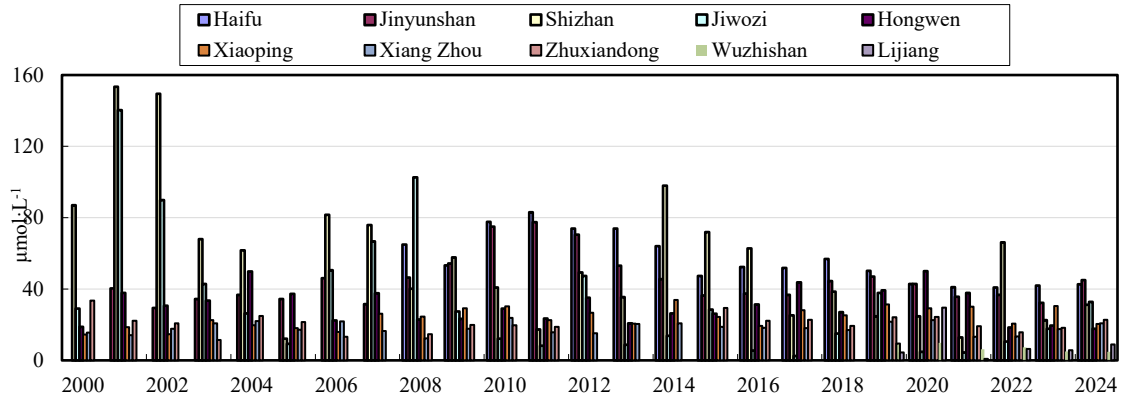


Figure 12. Annual average of NO_3^- concentration of all monitoring sites, EANET China

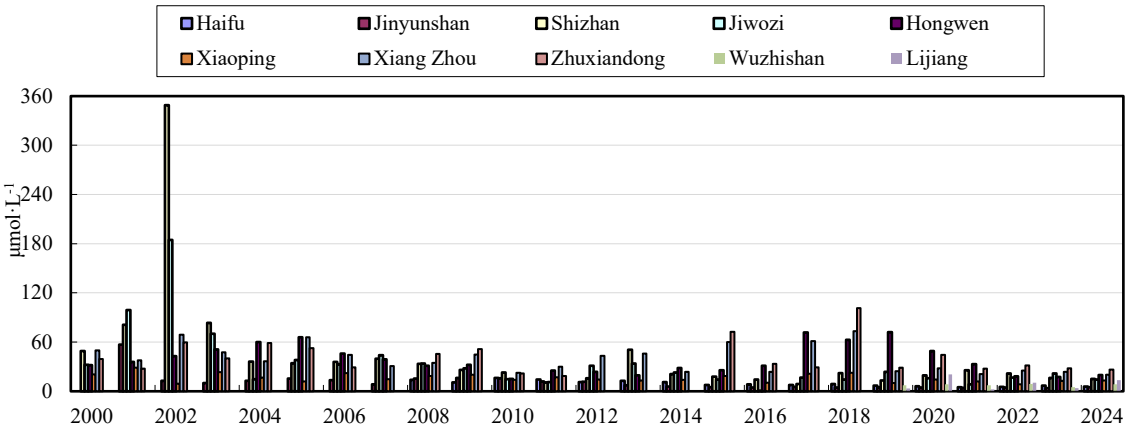


Figure 13. Annual average of Cl^- concentration of all monitoring sites, EANET China

Sulfate (SO_4^{2-}) and nitrate (NO_3^-) serve as the predominant acidic ions in wet deposition. Figure 14 illustrates the annual concentrations of these two major acidic ions at the four long-term EANET monitoring sites from 2000 to 2024, excluding Wuzhishan and Lijiang due to their shorter monitoring records. Over the 25-year observation period, the nationwide SO_4^{2-} concentration

across China's EANET network exhibited a distinct long-term downward trend. Meanwhile, the annual average NO_3^- concentration also experienced a slight declining tendency, with an overall decreasing magnitude considerably lower than that of SO_4^{2-}.

Further analysis of Figure 14 reveals a notable temporal variation in the relative concentrations of the two ions. Before 2015, SO_4^{2-} concentrations consistently remained higher than NO_3^- concentrations in wet deposition across China's EANET sites. Following a pronounced decline in SO_4^{2-} levels, the concentrations of the two ions gradually converged after 2015. In recent years, NO_3^- concentrations have even exceeded SO_4^{2-} concentrations at the monitoring sites. This phenomenon indicates highly effective reductions in atmospheric sulfur precursor emissions implemented in China over the study period. While nitrogen precursor emissions have also decreased moderately, their reduction has been far less pronounced due to greater control difficulties.

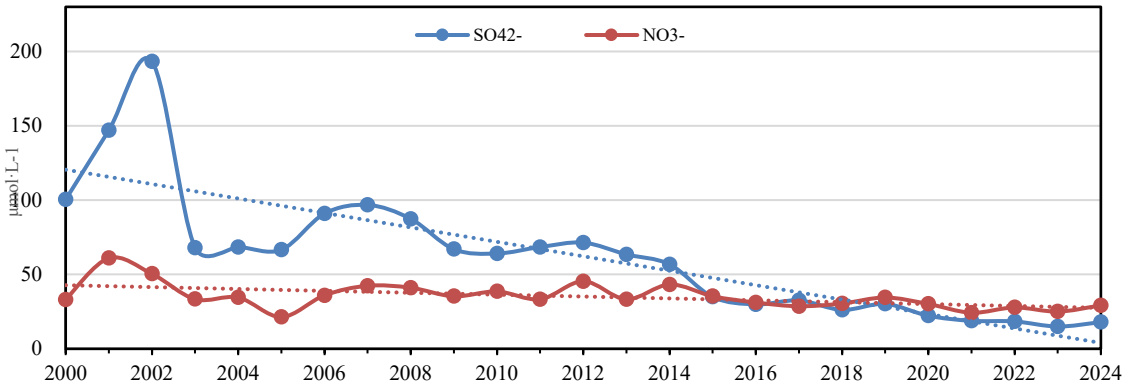


Figure 14. Trends of annual average of SO_4^{2-}& NO_3^- concentration overall EANET China

Figure 15 to Figure 19 illustrate the annual average concentrations of ammonium (NH_4^+), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) ions in wet deposition across China's EANET monitoring sites from 2000 to 2024. Spatially, rural and remote monitoring sites maintained relatively lower annual average cation concentrations than urban sites throughout the study period. In most years, inland cities including Xi'an and Chongqing exhibited higher annual average cation levels than other EANET monitoring sites. From a long-term perspective, Ca^{2+} and Mg^{2+} concentrations showed a slight overall downward trend, with particularly remarkable decreases observed at inland stations such as Xi'an and Chongqing. In contrast, the remaining cation ions presented no obvious long-term variation trends during the 25-year observation period.

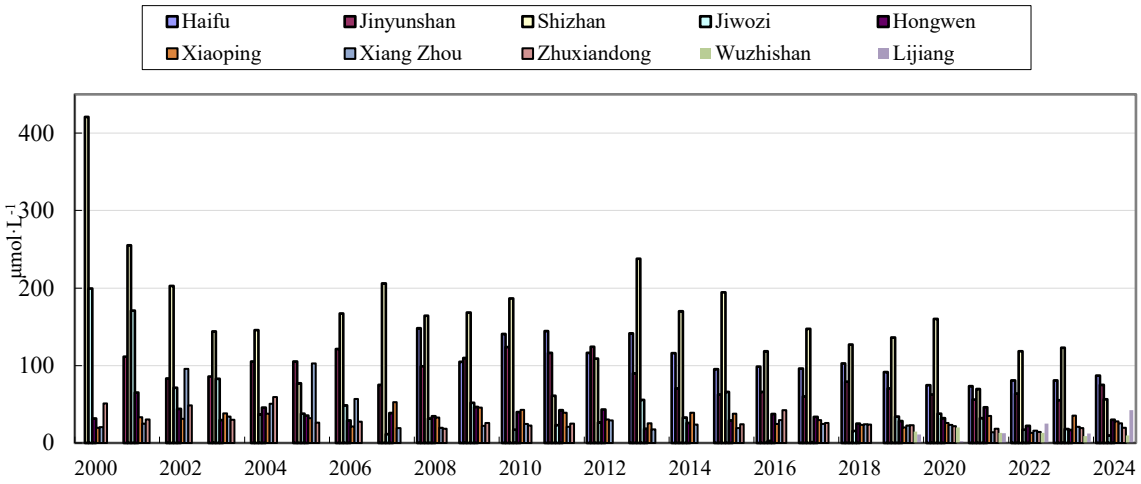


Figure 15. Annual average NH_4^+ concentration of all monitoring sites EANET China

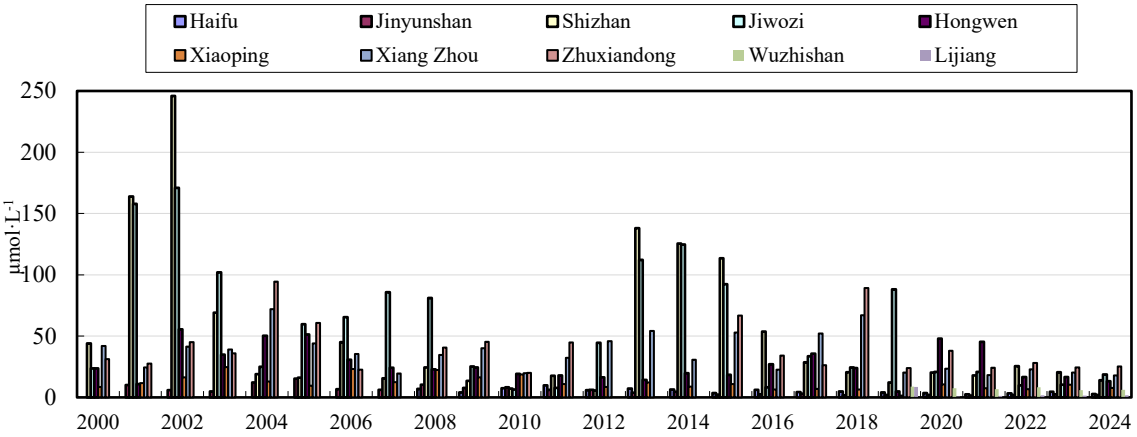


Figure 16. Annual average Na^+ concentration of all monitoring sites in EANET China.

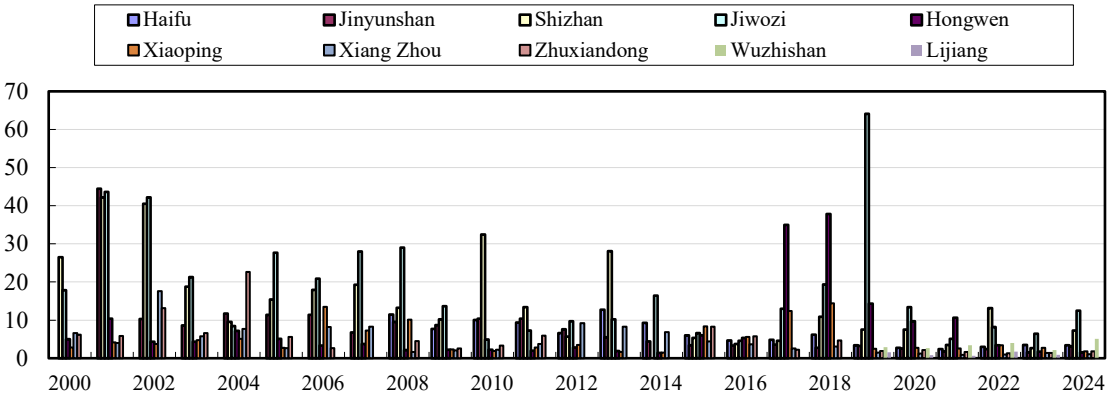


Figure 17. Annual average K^+ concentration of all monitoring sites in EANET China.

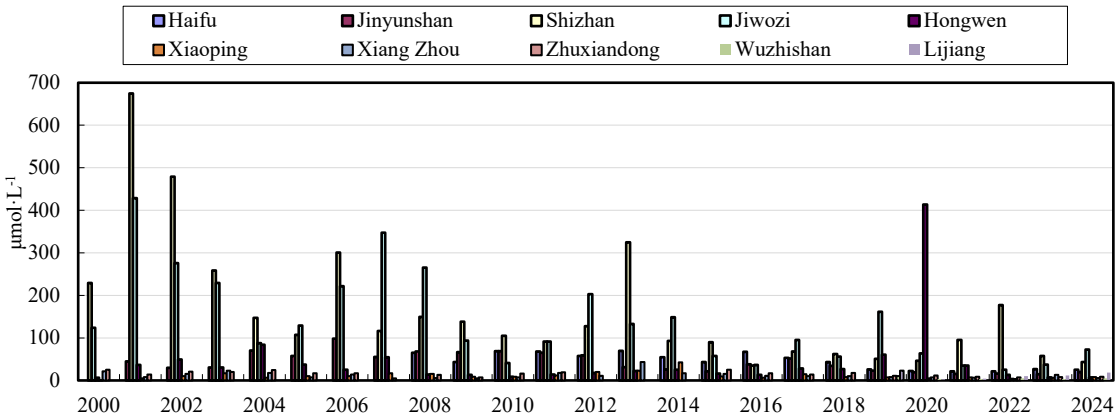


Figure 18. Annual average Ca^{2+} concentration of all monitoring sites in EANET China.

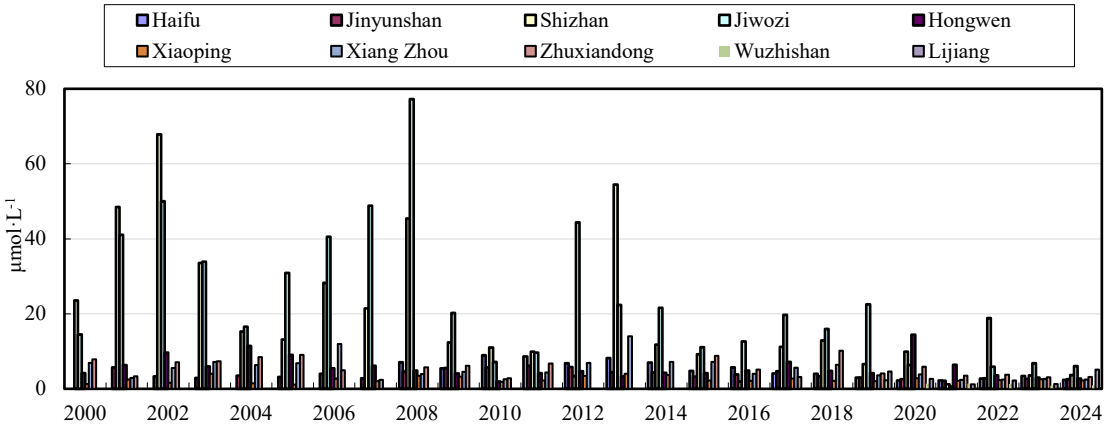


Figure 19. Annual average Mg^{2+} concentration of all monitoring sites in EANET China.

2.1.2 Dry deposition of EANET China

Dry deposition monitoring was initiated in 2001 at three representative sites: Jinyunshan in Chongqing, Hongwen in Xiamen, and Xiangzhou in Zhuhai. The Weishuiyuan site carried out dry deposition monitoring from 2001 to 2006 and subsequently suspended its monitoring operations, as the surrounding environmental conditions no longer satisfied the siting criteria for rural EANET monitoring stations. Accordingly, continuous dry deposition monitoring has been maintained at Jinyunshan, Hongwen, and Xiangzhou (renamed Haibin-park since 2012) throughout the 2000–2024 period, while Wuzhishan and Lijiang have been incorporated into the dry deposition monitoring network since 2019. All operational sites conduct hourly automatic atmospheric monitoring, covering key indicators including SO_2, NO_2 (or NO and NO_x), and PM_{10}. Furthermore, three long-term monitoring sites (Jinyunshan, Hongwen, and Xiangzhou) supplemented $PM_{2.5}$ and O_3 monitoring parameters during 2022–2024.

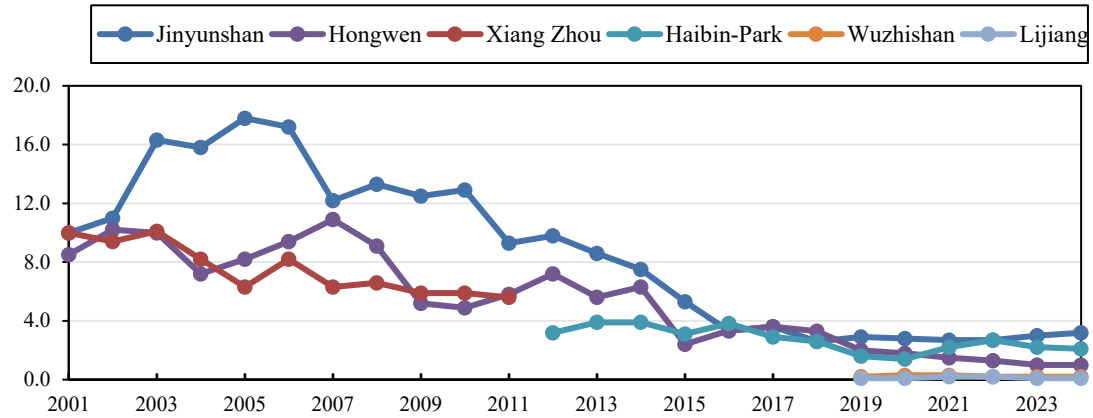


Figure 20. Trends of annual average of SO_2 concentration of EANET China in 2000-2024 (Unit: ppb).

Figure 20 illustrates the annual average SO_2 concentrations at seven dry deposition monitoring sites across the 2001–2024 period. The monitoring results show that SO_2 concentrations at Jinyunshan and Hongwen increased slightly from 2001 to 2007, followed by a prominent declining trend after 2008. By comparison, Xiangzhou (renamed Haibin-park since 2012) has exhibited a continuous downward trend since 2001. From 2019 to 2024, all long-term monitoring sites recorded their historically lowest SO_2 concentrations, which have stabilized within a range of 1–4 ppb. In terms of spatial discrepancies, Jinyunshan maintained the highest overall annual mean SO_2 concentrations among all sites, while Wuzhishan and Lijiang consistently presented extremely low levels of 0.1–0.3 ppb throughout the entire monitoring period.

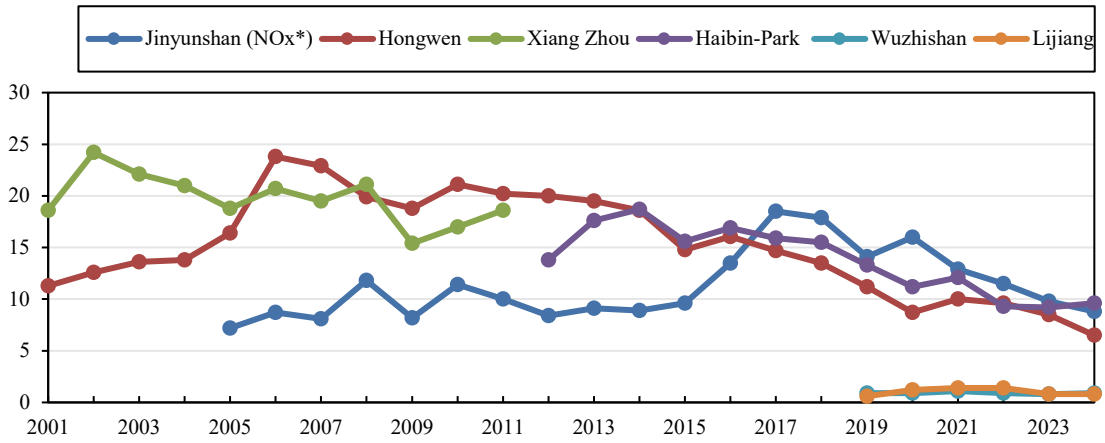


Figure 21. Trends of annual average of NO_2 and NO_X concentration of EANET China in 2000-2024 (unit: ppb).

Figure 21 illustrates the annual average NO_2/NO_x concentrations at six dry deposition monitoring sites over the 2001–2024 period. Overall, NO_2 concentrations at Xiangzhou (renamed Haibin-park since 2012) remained at relatively high levels throughout the monitoring period with an early fluctuating downward tendency, while the Hongwen site experienced an initial increase followed by a continuous decline in NO_2 concentrations. Jinyunshan maintained relatively low NO_x levels in the early observation stage, followed by a rapid increase after 2015, a peak in 2017, and a sustained

declining trend thereafter. From 2019 to 2024, NO_2/NO_x concentrations at all long-term monitoring sites decreased to their historically lowest levels and stabilized within the range of 6–10 ppb. In terms of spatial and temporal discrepancies, Xiangzhou dominated with higher concentrations in the early years, whereas Jinyunshan showed a notable concentration elevation in the later stage. By contrast, Wuzhishan and Lijiang consistently maintained extremely low NO_2 levels of 0.6–1.4 ppb across the entire study period.

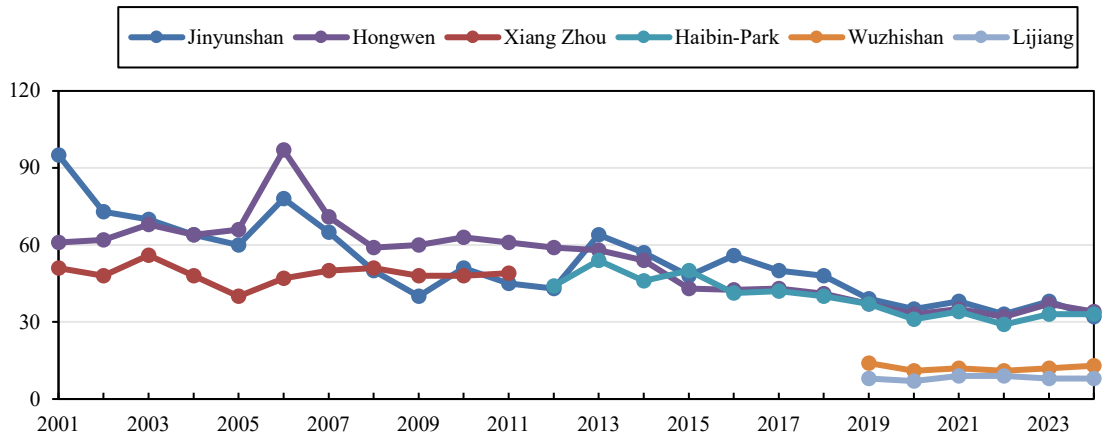


Figure 22. Trends of annual average of PM_{10} concentration of EANET China in 2000-2024 (unit: μg/m^3).

Figure 22 illustrates the annual average PM_{10} concentrations at seven dry deposition monitoring sites over the 2001–2024 period. Jinyunshan, Hongwen, and Xiangzhou (renamed Haibin-park since 2012) exhibited consistent temporal variations: PM_{10} concentrations fluctuated from 2001 to 2007 and then declined gradually after 2007. These three long-term sites all recorded a slight rebound in PM_{10} levels in 2013 before resuming a steady downward trend, with concentrations dropping to relatively low levels of approximately 33 μg/m^3 by 2024. Throughout the entire monitoring period, Wuzhishan and Lijiang consistently maintained extremely low PM_{10} concentrations, ranging from 7 to 14 μg/m^3.

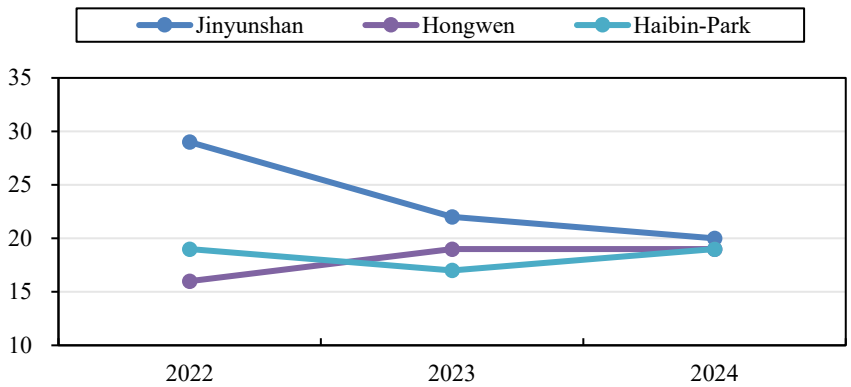


Figure 23. Trends of annual average of $PM_{2.5}$ concentration of EANET China (unit: μg/m^3).

Figure 23 illustrates the annual average $PM_{2.5}$ concentrations at three dry deposition monitoring sites over the 2022–2024 period. The monitoring results indicate that Jinyunshan recorded the

highest $PM_{2.5}$ concentrations among the three sites, presenting a steady downward trend from 29 μg/m^3 to 20 μg/m^3, with an overall reduction of approximately 30%. In comparison, Hongwen experienced a slight increase in $PM_{2.5}$ levels during the same period, while Haibin-park maintained generally stable concentrations. By 2024, $PM_{2.5}$ concentrations at the three monitoring sites had converged to a comparable level of around 20 μg/m^3.

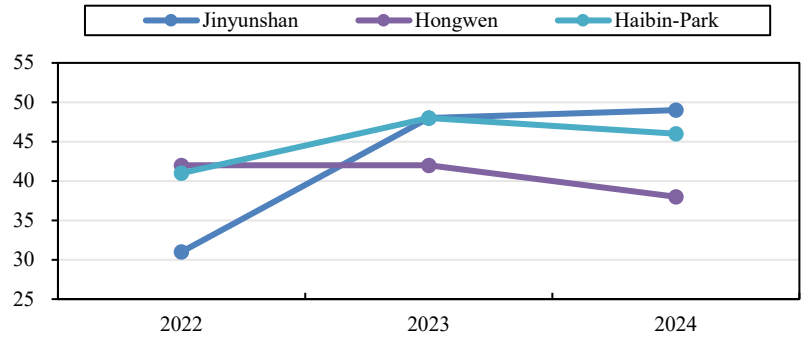


Figure 24. Trends of annual average of O_3 concentration of EANET China (unit: ppb).

Figure 24 illustrates the annual average O_3 concentrations at three dry deposition monitoring sites over the 2022–2024 period. Jinyunshan exhibited a remarkable increase in O_3 concentrations, rising from 31 ppb in 2022 to 48 ppb in 2023, representing an increase of over 50%, followed by a mild continuous growth in 2024. In contrast, Hongwen maintained stable O_3 levels in the early stage before experiencing a declining trend, while Haibin-park showed a slight increase followed by a marginal decrease. By 2024, Jinyunshan recorded the highest O_3 concentration at 49 ppb, whereas Hongwen presented the lowest level at 38 ppb among the three monitoring sites.

2.2 Inland water

Four inland water monitoring sites, namely Jinyunshan, Jiwozi, Xiaoping and Zhuxiandong, have been continuously operated since 2001 across the corresponding four EANET cities throughout the 2001–2024 period. The monitoring program covers water quality indicators with two distinct sampling frequencies. Specifically, pH, EC, alkalinity, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+} are sampled and analyzed on a quarterly basis, while color, transparency, NO_2^- and PO_4^{3-} are monitored annually.

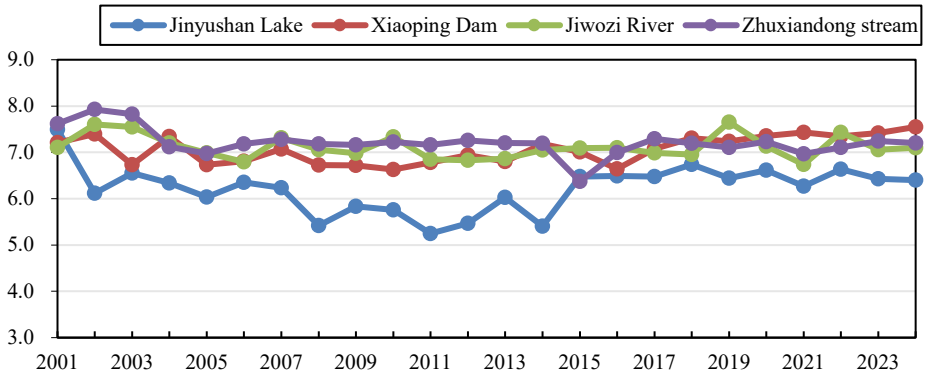


Figure 25. Annual Average pH Trends of inland water in EANET China（2000-2024）.

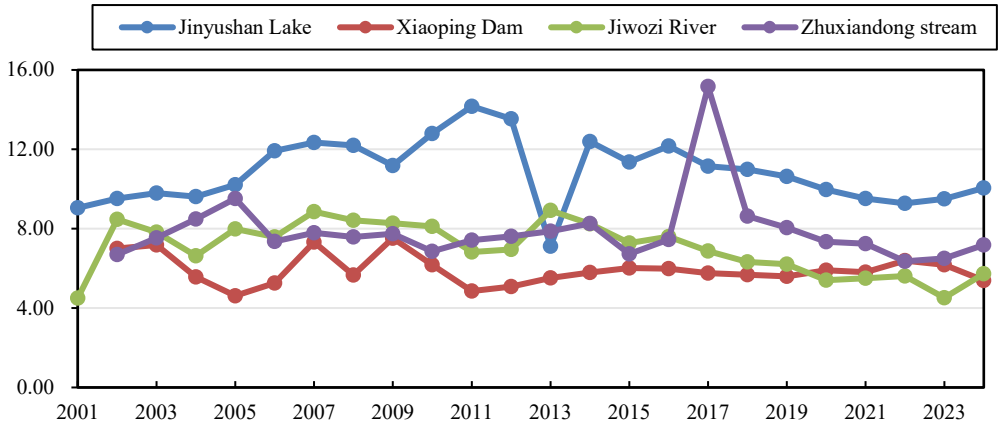


Figure 26. Annual Average EC Trends of inland water in EANET China（2000-2024）(unit: mS/m).

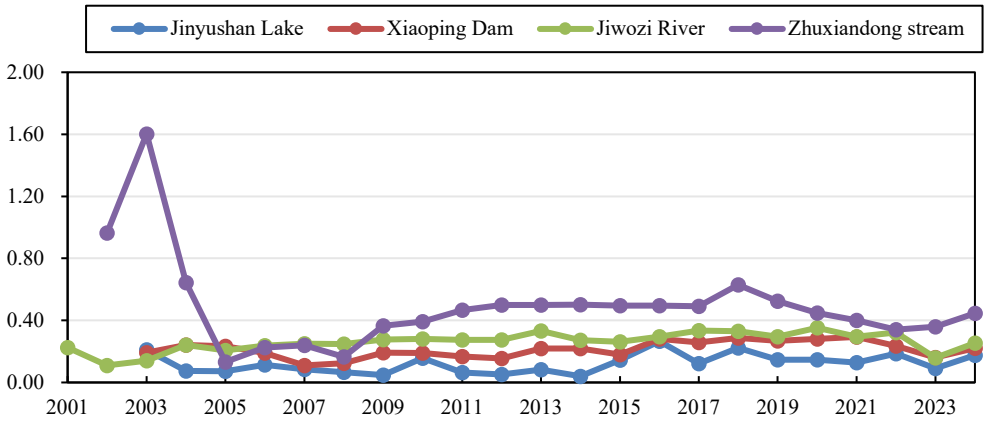


Figure 27. Annual Average alkalinity Trends of inland water in EANET China（2000-2024）(unit: meq/L).

Figure 25 to Figure 27 illustrate the annual average pH, EC, and alkalinity values at the four inland water monitoring sites from 2001 to 2024. Spatially, the Jinyunshan site presented relatively low annual average pH and alkalinity levels, accompanied by high EC values. The other three sites maintained highly consistent annual pH values with one another. Over the 24-year monitoring period, all four sites exhibited no distinct interannual variations in annual average pH and EC values. In terms of alkalinity, Jinyunshan, Jiwozi, and Xiaoping showed stable long-term trends throughout the study period. In contrast, Zhuxiandong recorded remarkably elevated alkalinity values from 2002 to 2004, which was likely attributable to the non-compliant environmental conditions of the monitoring site in the early stage that failed to meet standard EANET siting requirements.

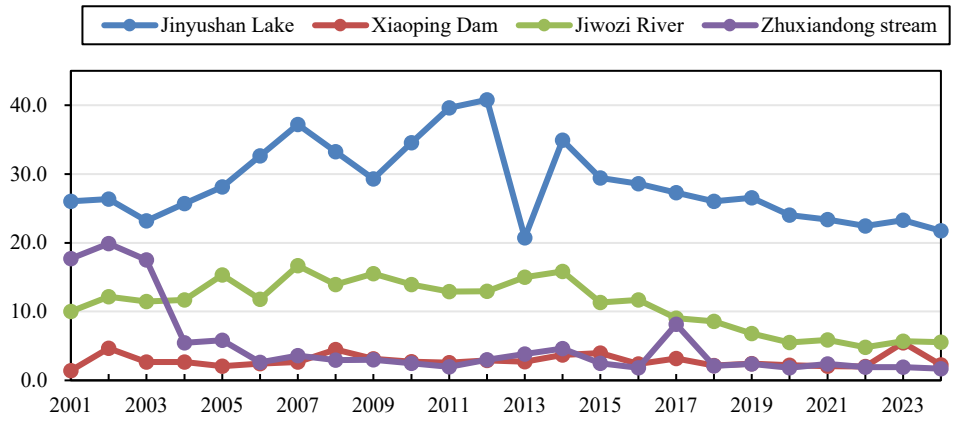


Figure 28. Annual Average SO_4^{2-} Concentration of inland water in EANET China （2000-2024） (unit: mg/L).

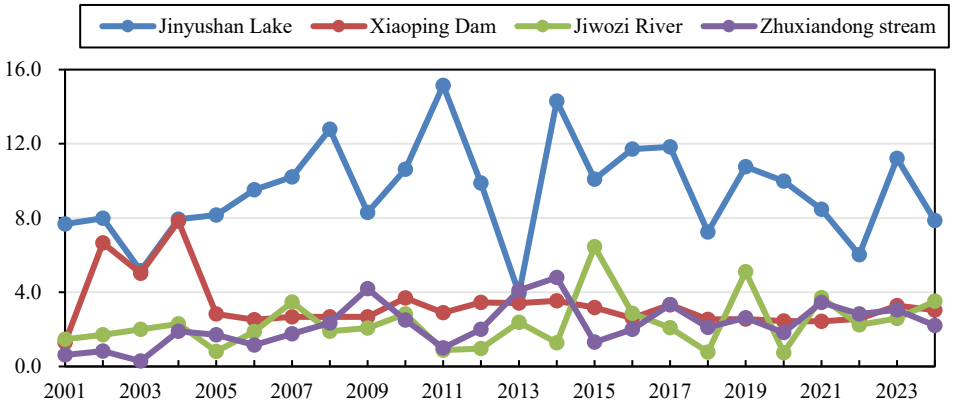


Figure 29. Annual Average NO_3^- Concentration of inland water in EANET China（2000-2024） (unit: mg/L).

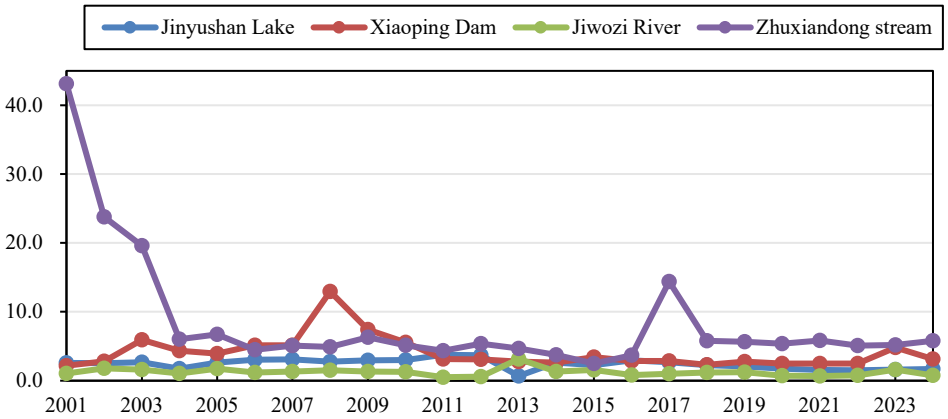


Figure 30. Annual Average Cl^- Concentration of inland water in EANET China（2000-2024） (unit: mg/L).

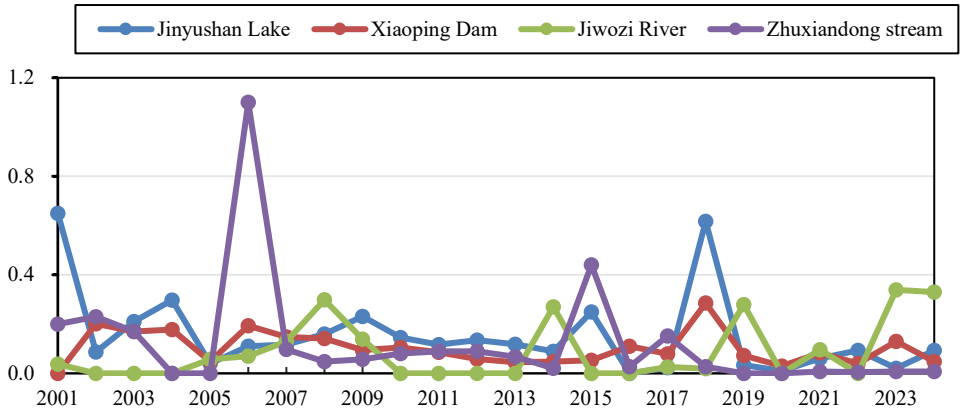


Figure 31. Annual average NH_4^+ Concentration of inland water in EANET China（2000-2024）(unit: mg/L).

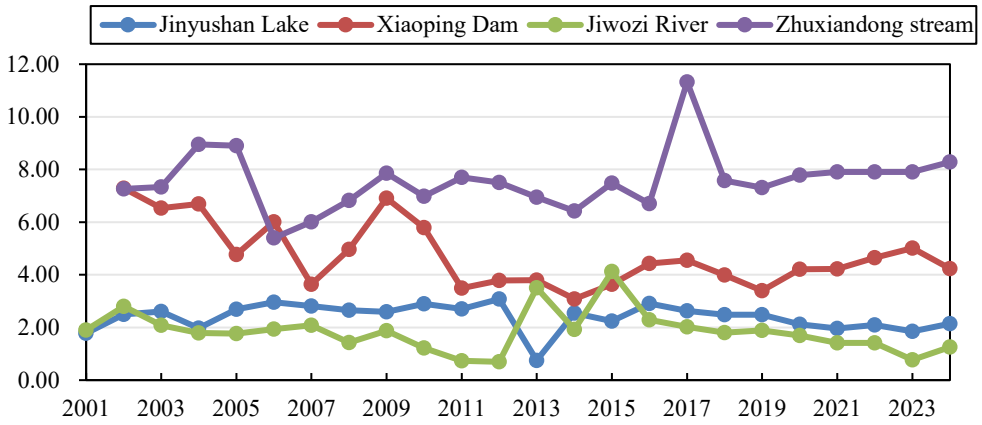


Figure 32. Annual average Na^+ Concentration of inland water in EANET China（2000-2024）(unit: mg/L).

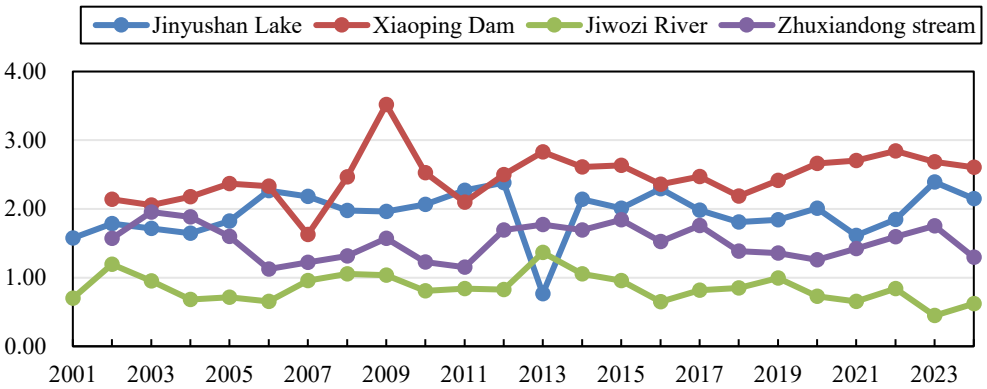


Figure 33. Annual average K^+ Concentration of inland water in EANET China (unit: mg/L).

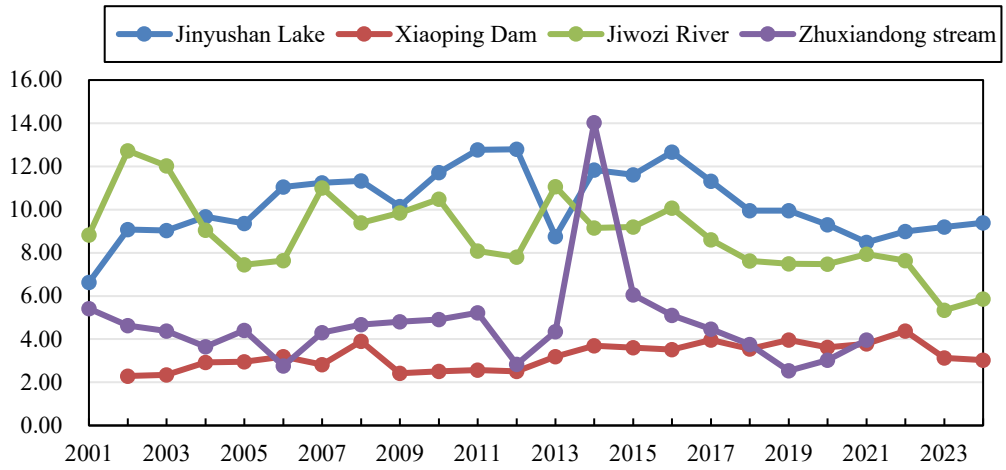


Figure 34. Annual average Ca^{2+} Concentration of inland water in EANET China (unit: mg/L).

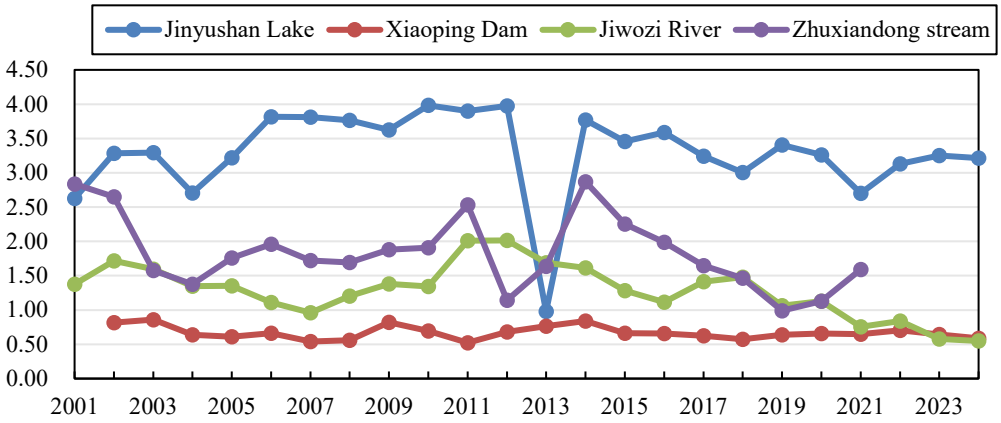


Figure 35. Annual average of Mg^{2+} Concentration of inland water in EANET China (unit: mg/L).

Figure 28 to Figure 30 illustrate the long-term trends in annual average concentrations of acidic ions (SO_4^{2-}, NO_3^- and Cl^-) at the four inland water monitoring sites over the 2001–2024 period. Similarly, Figure 31 to Figure 35 present the annual average concentration variations of major alkaline ions, including NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+}, across the same monitoring period.

Spatially, inland water monitoring sites located in Chongqing and Xi'an exhibited significantly higher concentrations of SO_4^{2-} and Ca^{2+}, but lower levels of Cl^- and Na^+, compared with coastal monitoring sites in Xiamen and Zhuhai. Among the four inland water monitoring stations, Jinyunshan in Chongqing recorded the highest annual average concentrations of SO_4^{2-}, NO_3^-, Ca^{2+} and Mg^{2+}. By contrast, Jiwozi in Xi'an presented the lowest annual average concentrations of Cl^-, Na^+ and K^+. The Xiaoping site in Xiamen had the maximum K^+ concentration and the minimum Ca^{2+} and Mg^{2+} concentrations across all four sites. Zhuxiandong in Zhuhai maintained relatively higher Cl^- and Na^+ levels. In addition, all four monitoring sites consistently showed low NH_4^+ concentrations throughout the study period.

2.3 Overall analysis

All six Chinese participating units of the EANET network strictly comply with relevant quality assurance and quality control (QA/QC) standards. The pass rates for the ion balance parameter (R1) and electrical conductivity (EC) parameter (R2) in rainfall analysis across the six EANET China sites from 2001 to 2024 indicate that R2 pass rates have consistently been higher than those for R1. Both parameters showed stable and consistent pass rates between 2011 and 2018 compared with the early period (2001–2006). A steady upward recovery trend was observed from 2021 to 2024, demonstrating sustained improvements in China's wet deposition data quality.

Annual average pH values at all 10 wet deposition monitoring sites across six cities ranged from 3.94 to 7.13. The lowest pH (3.94) was recorded at Jinyunshan in 2010, and the highest (7.13) at Shizhan in 2022. Xi'an exhibited the highest annual average pH values. Prior to 2010, Chongqing recorded the lowest values but showed a marked increase after 2010. Xiamen and Zhuhai (southeast coast) maintained comparable pH levels throughout. Wuzhishan and Lijiang fell within the mid-range. Rural and remote sites generally yielded lower pH than urban sites. A slight increasing trend was observed over the 25-year period, with a more pronounced upward tendency between 2010 and 2024. Since 2017, pH have remained relatively stable.

As for EC, Chongqing and Xi'an consistently maintained higher EC values than Xiamen, Zhuhai, Wuzhishan and Lijiang. Regional differences were particularly prominent from 2000 to 2014, after which EC in Chongqing and Xi'an decreased substantially, converging toward lower levels observed at other sites. The change in annual average EC of EANET China presented a clearly downward trend.

SO_4^{2-} and NO_3^- are the dominant acidifying ions in rainwater. Inland Chongqing and Xi'an recorded markedly higher concentrations than coastal cities, while chloride (Cl^-) levels were higher at coastal sites due to sea salt aerosol inputs. Rural sites always held lower anion loads than urban sites. From 2000 to 2024, national average SO_4^{2-} concentrations presented a prominent long-term downward trend, whereas NO_3^- only saw a mild decline with smaller reduction magnitude. Before 2015, SO_4^{2-} concentrations exceeded NO_3^- at nearly all stations, after sustained sulfur emission abatement, the two ion concentrations converged post-2015, and NO_3^- even surpassed SO_4^{2-} at many sites in recent years, indicating successful sulfur pollution control yet slower nitrogen emission mitigation progress. As for the cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}), rural and remote sites maintained lower cation concentrations, inland cities (Xi'an, Chongqing) exhibited higher levels. Ca^{2+} and Mg^{2+} showed a slight overall downward trend, with particularly notable decreases at inland stations. Other cations showed no obvious long-term variation.

In terms of dry deposition, SO_2 at early monitoring sites climbed slightly from 2001–2007 before a dramatic post-2008 decline. Xiangzhou and Haibin-park sites maintained a continuous downward trend starting in 2001. All long-term stations hit historical low levels (1–4 ppb) during 2019–2024. Jinyunshan recorded the country's highest SO_2 levels, whereas Wuzhishan and Lijiang retained ultra-low concentrations (0.1–0.3 ppb). As for NO_2/NO_x, Xiangzhou featured relatively high early concentrations with fluctuating decreases, Hongwen rose moderately first then declined persistently. Jinyunshan's NO_x increased rapidly after 2015, peaked in 2017, and fell steadily afterward. From 2019 to 2024, all mature stations stabilized at 6–10 ppb, while Wuzhishan and Lijiang remained at 0.6–1.4 ppb. As for the PM_{10} data, there was an obvious downward trend in the sites of Jinyunshan,

Hongwen and Haibin-Park after the year of 2013 and dropped to around 33 ppb by 2024. Wuzhishan and Lijiang maintained ultra-low PM_{10} (7–14 ppb) across all years.

As for inland water monitoring from 2001 to 2024, all sites showed no obvious long-term interannual trends in pH and EC, only Zhuxiandong Stream had abnormally high alkalinity in 2002–2004 due to early non-compliant site conditions. Distinct spatial ionic disparities existed across monitoring waters: inland Chongqing and Xi'an sites featured higher SO_4^{2-} and Ca^{2+} but lower Cl^- and Na^+ than coastal Xiamen and Zhuhai stations, with Jinyunshan Lake recording the highest SO_4^{2-}, NO_3^-, Ca^{2+} and Mg^{2+} concentrations, Jiwozi River the lowest Cl^-, Na^+ and K^+, Xiaoping Dam the maximum K^+ and minimum Ca^{2+} and Mg^{2+}, and Zhuxiandong Stream relatively high Cl^- and Na^+, while ammonium levels stayed persistently low at all four inland water bodies throughout the monitoring period.

Chapter 3 Review of Major Policy Documents on Air Pollution

Between 2020 and 2024, China issued a series of important policies and documents to intensify air pollution control and continuously improve ambient air quality. In 2021, the 14th Five-Year Plan for Ecological and Environmental Protection sets clear targets for cutting pollutant emissions and improving air quality, which also emphasizes the coordinated control of multiple pollutants and the synergistic reduction of greenhouse gas emissions and air pollutants. In 2022, the Action Plan for Deepening the Battle Against Heavily Polluted Weather, Ozone Pollution and Diesel Truck Pollution was released, providing implementation guidance for local governments. Furthermore, the new Action Plan for Continuous Improvement of Air Quality was issued in 2023, which outlined a new round of tasks for the coordinated governance of key air pollutants. These policies collectively constitute a comprehensive institutional framework for atmospheric environmental management, driving sustained and notable improvements in China's air quality.

1. The 14th Five-Year Plan for Ecological and Environmental Protection

Issued by the State Council in November 2021, the 14th Five-Year Plan for Ecological and Environmental Protection is a comprehensive five-year special plan covering national ecological and environmental protection work from 2021 to 2025. It takes air quality improvement as a core binding development indicator, coordinates the joint governance of air, water, soil and solid waste pollution, and forms deep alignment with the national carbon peaking and carbon neutrality strategy. Taking 2020 as the baseline year, the plan allocates mandatory air pollutant emission reduction tasks nationwide and in key regions including Beijing-Tianjin-Hebei region and surroundings areas, Fenwei Plain and the Yangtze River Delta, and defines quantified multiple targets by 2025, covering $PM_{2.5}$ concentration, air quality achievement days, heavily polluted days, and emission of nitrogen oxides and VOCs. It arranges systematic governance projects centering on industrial structural upgrading, clean energy replacement, clean retrofits of mobile pollution sources, industrial ultra-low emission transformation, and refined control of dust and agricultural ammonia, guiding all provinces and municipalities to formulate local air governance implementation plans. The document serves as the general implementation roadmap for air quality improvement throughout the 14th Five-Year Plan period.

2. Action Plan for Deepening the Battle Against Heavily Polluted Weather, Ozone Pollution, and Diesel Truck Pollution

Jointly issued by 15 ministries and commissions led by the Ministry of Ecology and Environment, National Development and Reform Commission and Ministry of Industry and Information Technology in November 2022, this Action Plan is a special implementation document to deliver the central government’s opinions on tough pollution prevention battles, formulating segmented targeted measures addressing three prominent bottlenecks of China’s compound air pollution. The plan sets quantified phased targets for 2025 under three sections: elimination of heavily polluted days, ozone pollution control and diesel truck pollution. It targets the regional $PM_{2.5}$ pollution in autumn and winter, continuous rise of ozone concentration in summer and autumn, and high emissions of nitrogen oxide from on-road and off-road mobile sources respectively. The document adopts region- and period-specific regulation and establishes differentiated emission reduction mechanisms based on enterprise performance grading to avoid one-size-fits-all governance. It also requires the development of a full closed-loop supervision system covering vehicles, fuel, roads

and enterprises. Supported by guarantee measures including monitoring capacity development, subsidies for raw material source substitution and special supervision inspections, the plan specifically addresses weak links in refined air pollution supervision and acts as a practical guiding document for targeted governance in segmented fields of the Blue Sky Campaign.

3. Action Plan for Continuous Improvement of Air Quality

Issued by the State Council on November 30, 2023, the Action Plan for Continuous Improvement of Air Quality, also known as the 3rd National Ten-Point Air Quality Action Plan, is the core top-level action plan for national air environmental governance from 2023 to 2025. Building on achievements of the previous two rounds of Blue Sky Campaigns, it advances two core priorities in tandem: coordinated control of $PM_{2.5}$ and ozone, and synergistic efficiency gains from pollution reduction and carbon mitigation. Taking 2020 as the baseline, the plan sets unified mandatory national emission reduction indicators and stricter differentiated regulatory targets for key urban agglomerations. It arranges comprehensive governance tasks across nine dimensions: industrial green transformation, clean and low-carbon energy development, green transport system construction, refined control of dust and agricultural non-point sources, full-process control of industrial ultra-low emissions and VOCs, cross-regional joint prevention and control, and targeted emergency response on heavily polluted days. The document further enforces local governments' primary responsibility for air quality improvement, establishes long-term management mechanisms including monthly coordination, cross-regional joint law enforcement and enterprise performance upgrading, and forms a modern air governance system covering the whole chain of pollution sources, production processes and terminal treatment, serving as the core implementation guideline for continuous national air quality improvement at the current stage.